Zhe Jian University

Research Seminar

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Advancing Mechatronics Technologies for Bio-Instrumentation and Control

XiaoQi Chen (陈小奇), PhD, Assoc Prof
Director, Mechatronics Engineering
Email: xqchen@canterbury.ac.nz

10 December 2008

New Zealand is located in the South Pacific between the Pacific Ocean and the Tasman Sea, between latitude 35 and 45 degrees south.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Liveable Place

- In 1996, Christchurch was acknowledged as the outstanding garden city from 620 international entries.
- In 1997, Christchurch was judged Overall Winner of Major Cities in the Nations in Bloom International Competition to become 'Garden City of the World'!

"I think every person….. dreams of finding some enchanted place of beautiful mountains and breathtaking coastlines, clear lakes and amazing wildlife. Most people give up on it because they never get to New Zealand"

Mr. Bill Clinton – Former US President
Gala Dinner, Christchurch, NZ 2000


Dr XiaoQi Chen's Office
Dept of Mech Eng
University of Canterbury

Agenda

- Who are involved?
- Overview of Mechatronics@UC
- Wall Climbing Robot using Non-Contact Adhesion
- Microrobotic Cell Injection
- Force Pattern Characterization of C. elegans
- Conclusions

Who are involved

- Supervising Team:
  - Assoc Prof XiaoQi Chen (Director for Mechatronics) - robotics, mechatronic systems
  - Prof J Geoff Chase - dynamics and control, bioengineering, structural
  - Dr Wenhui Wang - robotics, bio-mechatronics
  - Dr Stefanie Gutschmidt - dynamics and vibration
  - Dept of Electrical Engineering, Computer Science, MacDiarmid, HITLab, Bioengineering Centre
- Technical Support
  - Mechatronics and electronics technicians: Rodney Elliot, Julian Murphy, Julian Philips,
  - Mechanical workshop
- Postgraduates
  - James Pinchin, PhD - Low-cost GPS based attitude solution using multiple software based receivers.
  - Patrick Wolm, MEng – Dynamic stability control of front wheel drive wheelchairs.
  - Scott Green, PhD - Human Robot Collaboration Utilising Augmented Reality
  - Ali Ghanbari, PhD – MEMS actuation and precision micromanipulation.
  - Mostafa Nayyerloo, PhD, – Structural health monitoring
  - Chris Hardie, MEng – biologically inspired robots
  - Matthew Keir, PhD – Head motion tracking, graduated in 2008
- Visiting Researchers / Fellows
  - Prof Richard King, Oregon Institute of Technology, Jun 2006 – Mar 2007
  - Prof Clarence de Silva, University of British Colombia, 1-31 August 2008
  - Australian DEST Endeavour Fellowship, Mr Ben Horan, Aug – Dec 2008. Haptics technology
- Interns
  - Julien Dufeu, Institut Francais de Mecanique Avancee (IFMA), 2007. Modelling of wall climbing device
  - Matthias Wagner, the University of Munich, 2007. Design of wall climbing robot.
  - Nikolas Schaal, The University of Stuttgart, 2007. Design of underwater vehicle.
  - Richard Engelaar, Eindhoven University of Technology, 2008. underwater vehicle.
  - Johan Vervoort, Eindhoven University of Technology, 2008. underwater vehicle.
  - Harald Zophoniasson, ENISE, France, 2008. High-precision motorised stage
- Industrial Collaborators
  - Geospatial Research Centre, Dynamic Controls Limited, Industrial Research Limited (IRL), Commtest, etc.

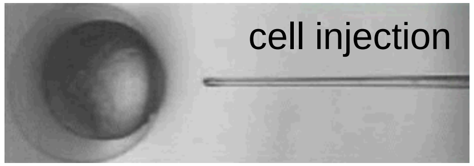
Mechatronics@UC

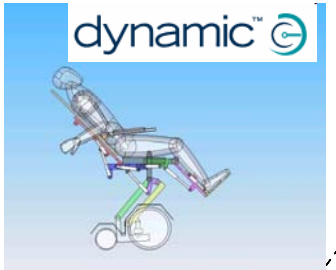
Bio-mechatronics

- Assistive devices for rehabilitation
- Bio-micromanipulation – cell injection

Burwood Academy of Independent Living

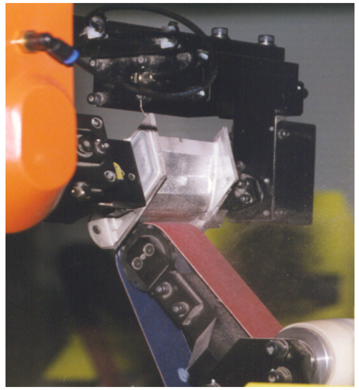
INDUSTRIAL RESEARCH LIMITED

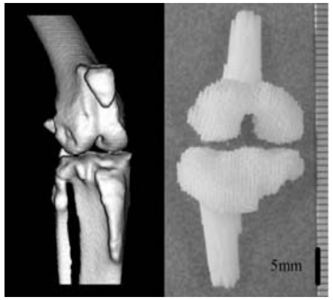




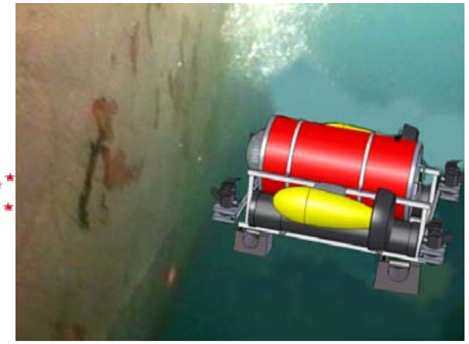
Instrumentation and Automation

- Manufacturing
- Structural control
- Energy harvesting
- Bio-scaffolding





NIWA
Taihoro Nukurangi

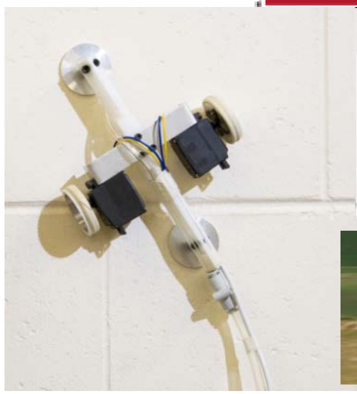


HITLabNZ

Geospatial Research Centre

Mobile Robotics

- Unmanned aerial vehicle, micro air vehicle
- Underwater vehicle for bio-security inspection
- Wall-climb robot for tank welding

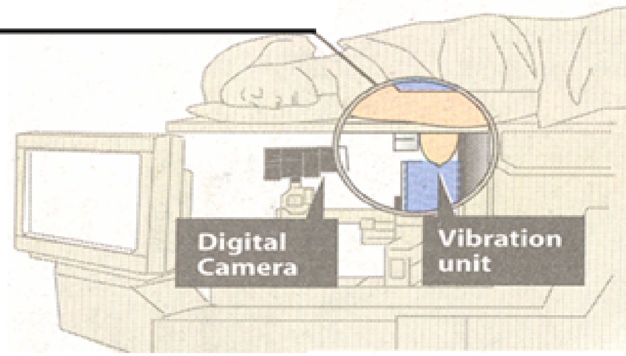


Digital Image-Based Elasto-Tomography

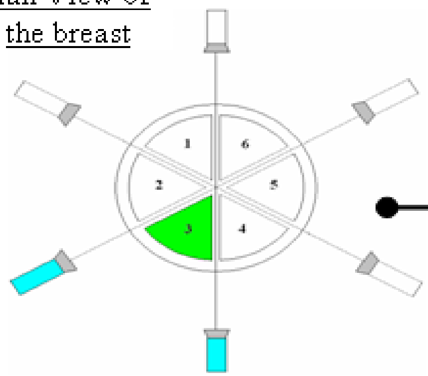
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

The DIET system is broken down into 4 fundamental steps: (1) Actuation → (2) Image Capture → (3) Motion Tracking and measurement → (4) Tissue stiffness reconstruction

1. A woman's breast is vibrated by an actuator and imaged with high-resolution digital cameras.

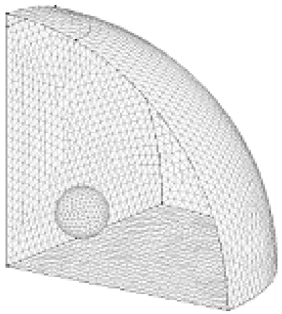


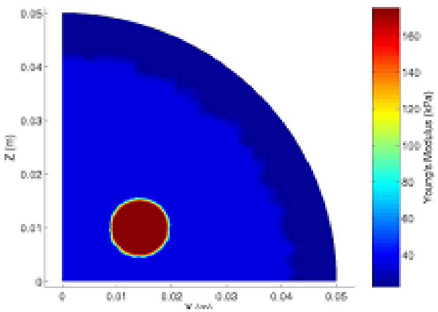
Plan View of the breast



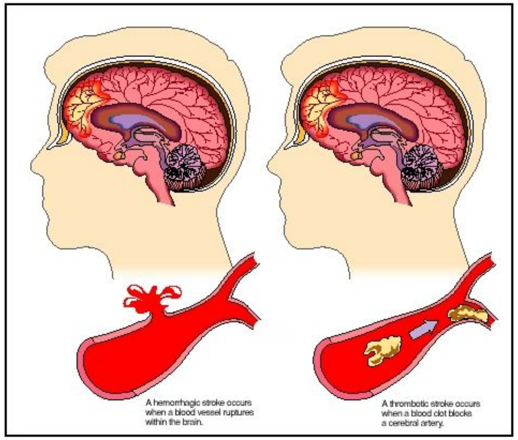
2. Spatially calibrated digital cameras combined with a motion sensor measures the surface motion of the breast.

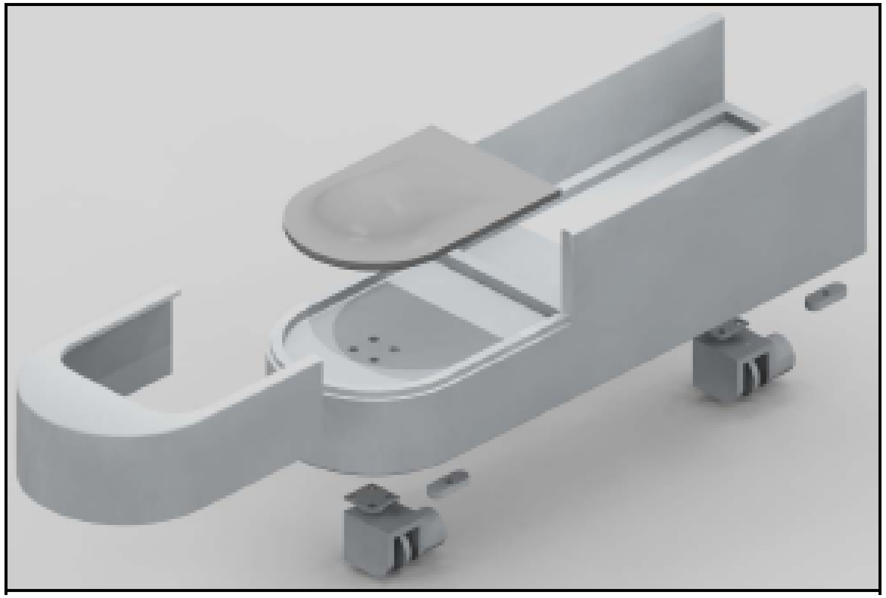
3. Finite Element method converts the measured breast surface motion into a 3-D stiffness distribution, where regions of high stiffness suggest cancer.





Variable Resistance Rehabilitation Device

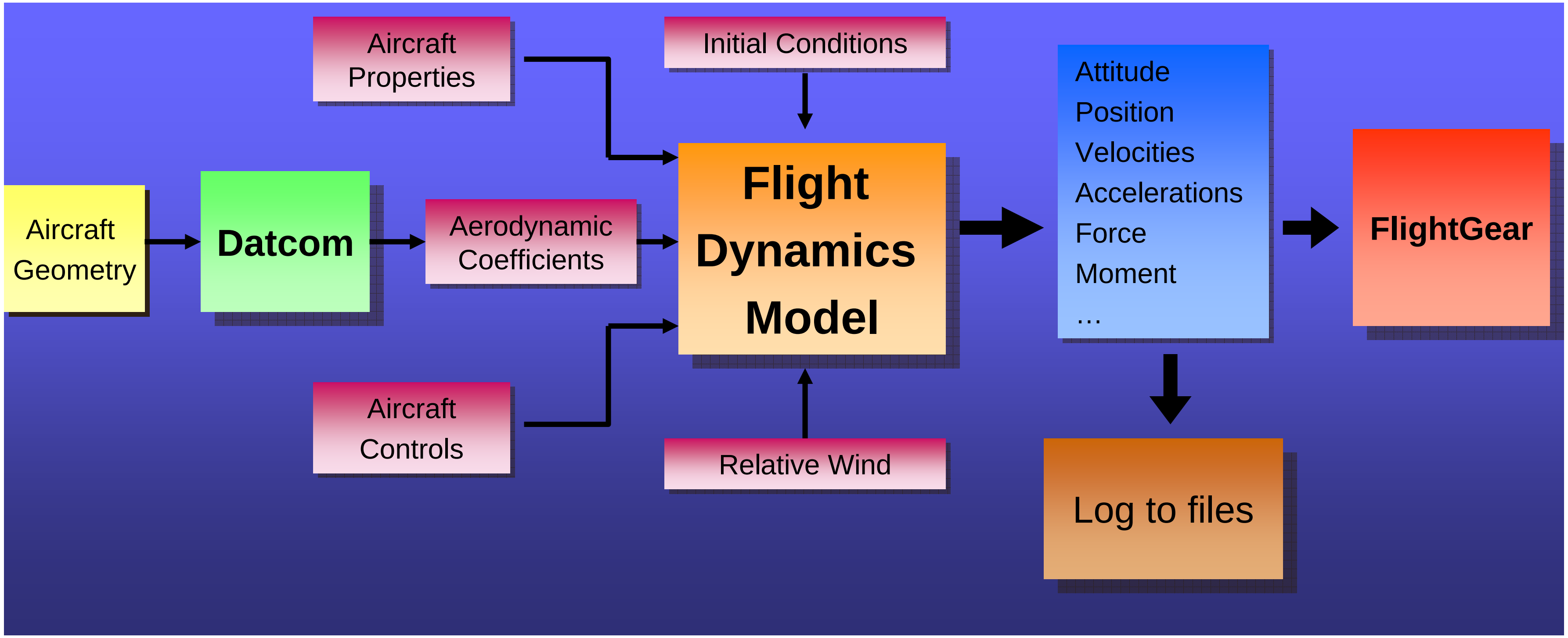




Provisional Patent (2008)

Integrated Flight Dynamics Model

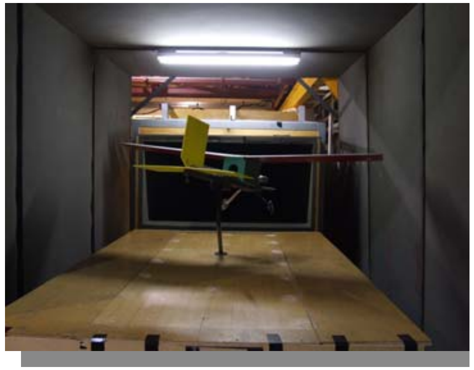
- The input of aircraft geometry instead of aerodynamic coefficients greatly simplified aircraft model development
  - ➢ No wind tunnel testing is required
  - ➢ Effects on changing aircraft geometry can be seen immediately
  - ➢ Much better repeatability

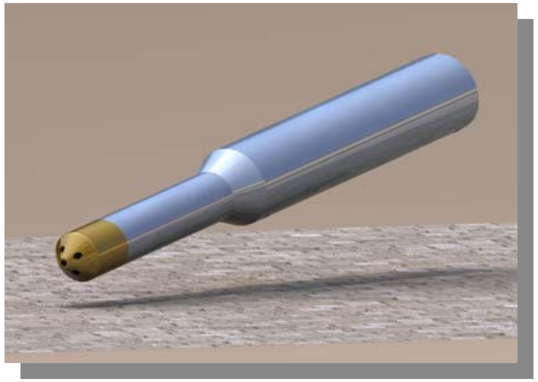


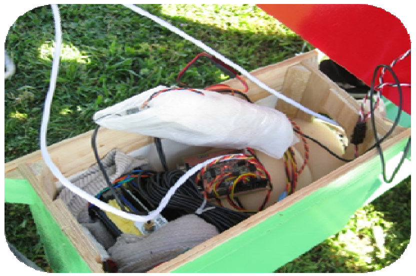
Q. Ou, X.Q. Chen, D. Park, A. Marburg, and J. Pinchin (2008), "Integrated Flight Dynamics Modelling for Unmanned Aerial Vehicles". Proc 2008 ASME/IEEE International Conference on Mechatronic and Embedded Systems (MESA08), Part of ASME International Design Technical Conf (DETCON), Beijing, China, October 12-15.

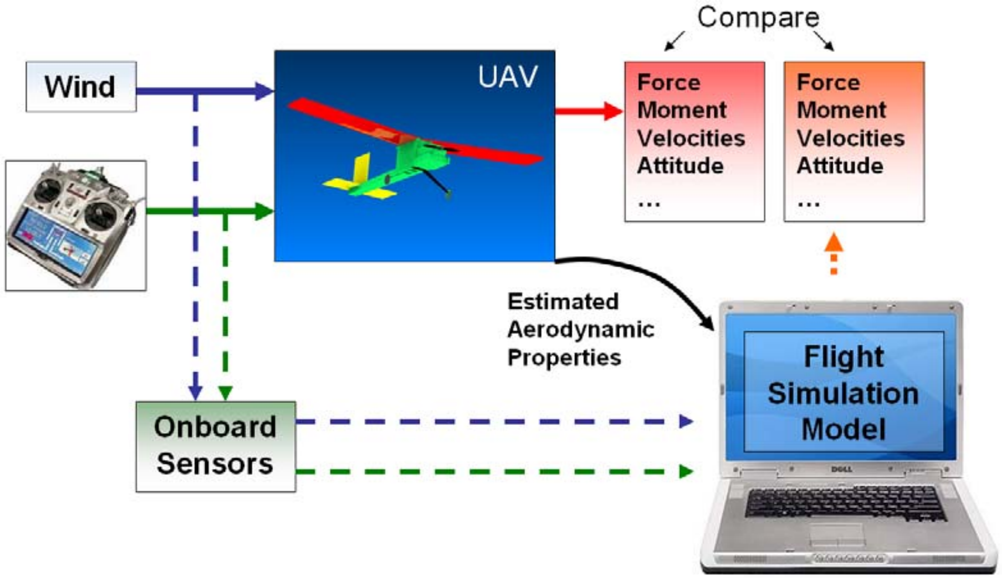
FDM Validation with On-Board Instruments

- Equipment used
  - 2.4 meter wing-span gas powered RC plane
  - GPS base station
  - Inertia navigation system
  - Servo pulse acquisition device
  - Wind speed sensor
  - Data logger
  - Wind tunnel







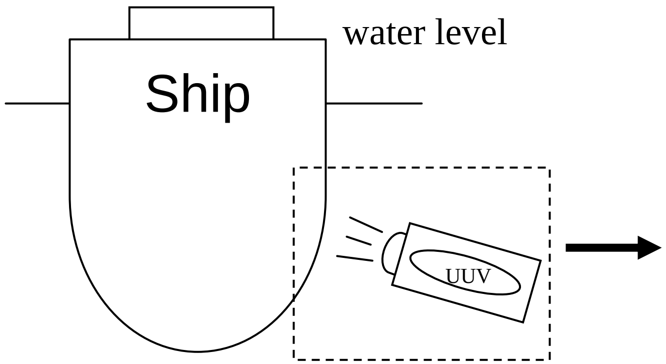


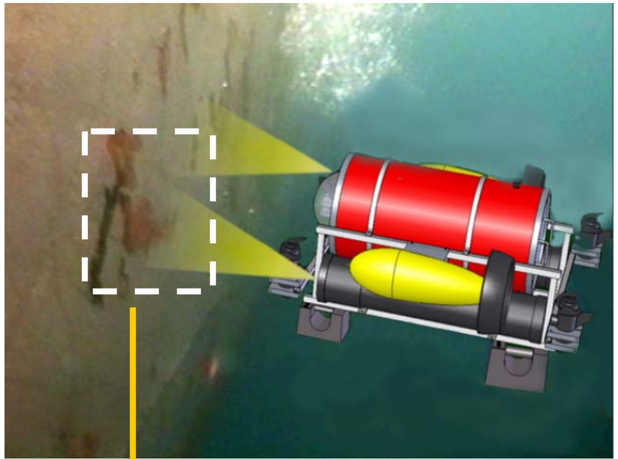
Video: UAV Test

D. R. Wong, Q. Ou, M. Sinclair, Y. J. Li, X. Q. Chen, A. Marburg (2008). **"Unmanned Aerial Vehicle Flight Model Validation Using On-Board Sensing and Instrumentation", 15**th Intl Conf on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, Dec 2-4, CD-ROM.

Canterbury UUV - Biosecurity

For shallow waters, up to 20m depth



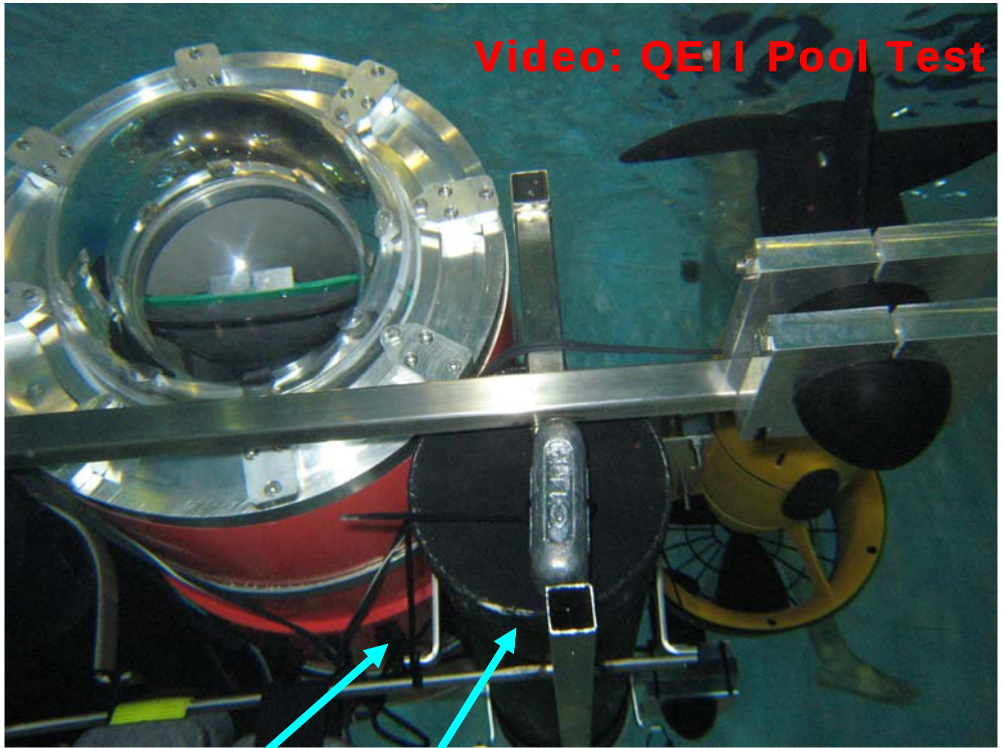


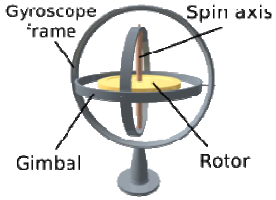
sea chest

W.H. Wang, R.C. Engelaar, X.Q. Chen & J.G. Chase, “The State-of-Art of Underwater Vehicles – Theories and Applications” *Mobile Robots - State of the Art in Land, Sea, Air, and Collaborative Missions*, Editors: X.Q. Chen, Y.Q. Chen, and J.G Chasse, ISBN 978-3-902613-39-4, I-Tech Education and Publishing, Vienna, Austria. (In press).

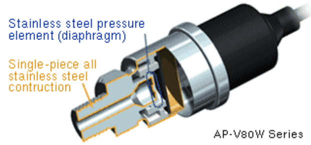
Vehicle design and electronics

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND



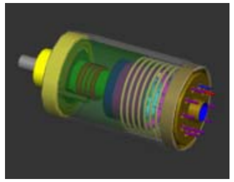


IMU



Pressure sensor-depth

Webcam



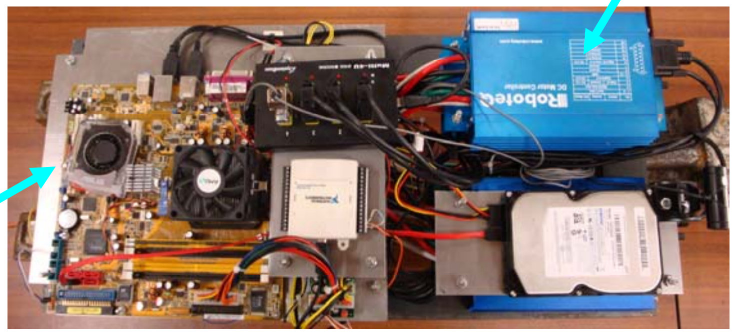
Temperature sensor

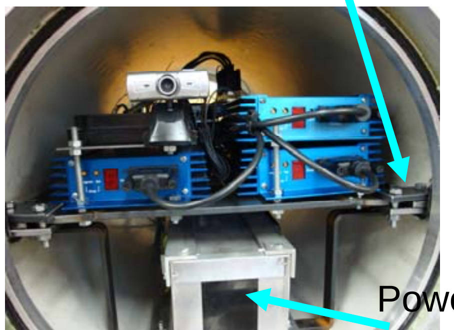
RoboteQ motor controller

Sliding mechanism

cable and canister seals

Mother board





Power supply

Back

A Novel Wall Climbing Robot using Non-Contact Adhesion

ScienceAlert
Australia & New Zealand

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Home | News | Features | Opinions | Events | Jobs

Wall-climbing robot breakthrough

Sunday, 19 August 2007

University of Canterbury

Robotic research at the University of Canterbury has climbed new heights with the development of a wall-climbing robot.

The robot has been developed by a team of researchers lead by Associate Professor XiaoQi Chen in the University's Mechanical Engineering department.

- **Motivation**
- **The Bernoulli Effect**
- **Design Considerations**
- **Perforamce**

BIOMIMICRYNEWS

Recent News | Archives | Tags | About | Newsletter | Submit News | Links | Subscribe

Engineers design robot capable of climbing walls (8/21/2007)

M. Wagner, X.Q. Chen, W.H. Wang, and J.G. Chase (2008), "A novel wall climbing device based on Bernoulli effect", Proc 2008 IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA08), ISBN: 978-1-4244-2368-2, Beijing, China, October 12-15, pp. 210-215. (Best Student Paper Award).

Motivation

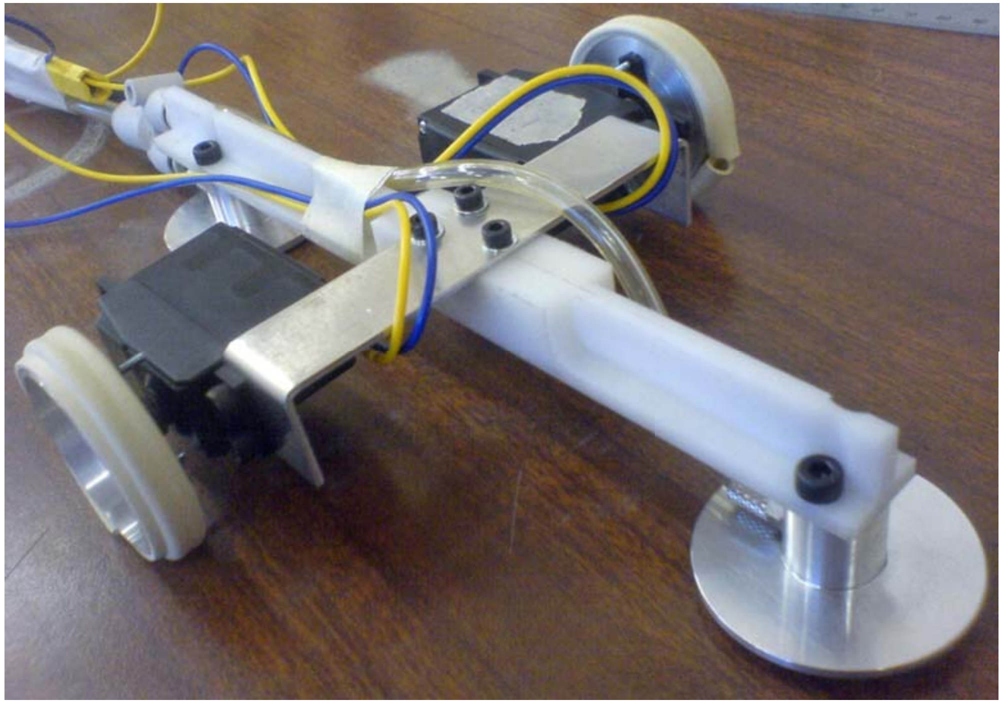
UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Adhesion		**Surface Conditions**
Magnetic	→	Ferromagnetic
Vacuum	→	Smooth, Non-permeable
Microfibre	→	Clean

Adhesion effect independent of materials and surface conditions is desirable

Challenge

Develop a Wall Climbing robot insensible to surface conditions
Adhesion device using air pressure to create attraction force



The Bernoulli Effect

Assumptions to simplify equations:

Laminar, steady, frictionless flow, viscous effects are neglected, incompressible fluid, only forces acting are pressure and weight

$$\frac{v^2}{2} + \frac{p}{\rho} + gh = const$$

Bernoulli equation:

$$\frac{v_1^{\ 2}}{2} + \frac{p_1}{\rho} + gh_1 = \frac{v_2^{\ 2}}{2} + \frac{p_2}{\rho} + gh_2$$

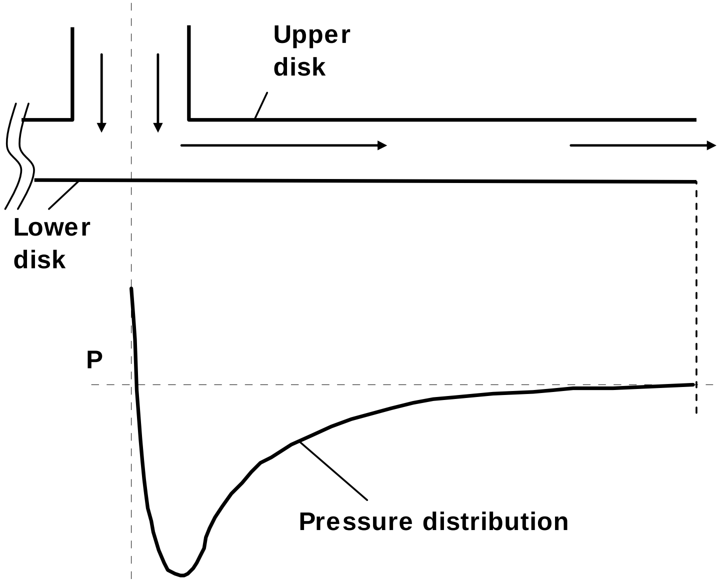
The Bernoulli Effect (Bernoulli‘s Principle):

$$\rho \frac{v^2}{2} + p = const$$

The pressure decreases with a simultaneously increasing velocity

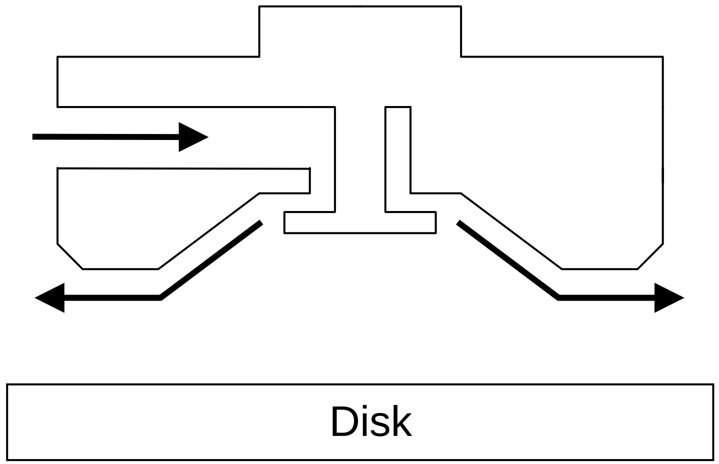
Design Considerations

Existing Devices



- Very small attraction force

NCT device



- Heavy
- High flow rate

More efficient lightweight device is needed

The Final Bernoulli Pad

Material: Aluminium

Number of parts: 2

Undercut: 0.5mm

Nozzle gap: 0.10mm

Diameter: 45mm

Height: 18mm

Total weight: 19g

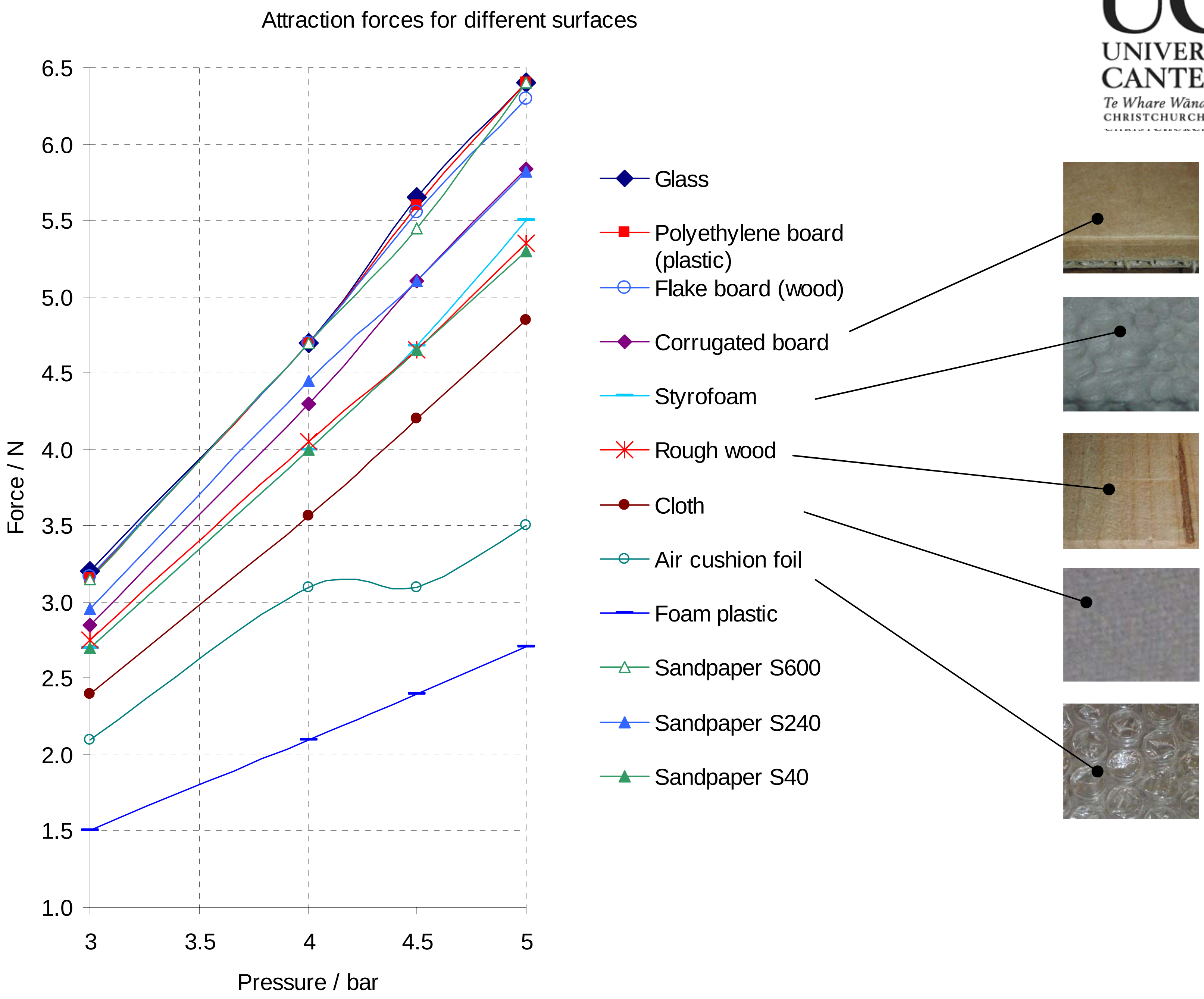
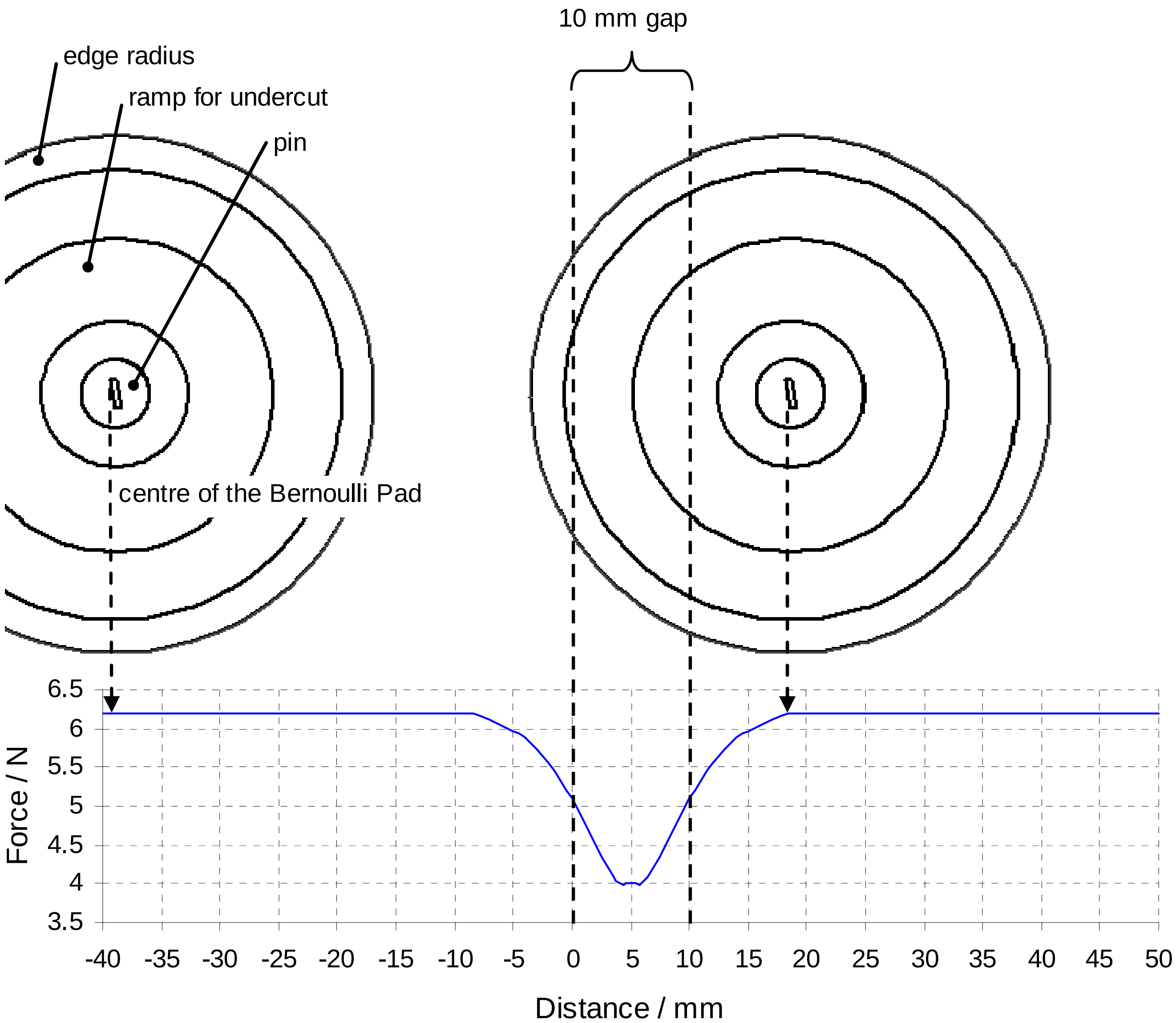
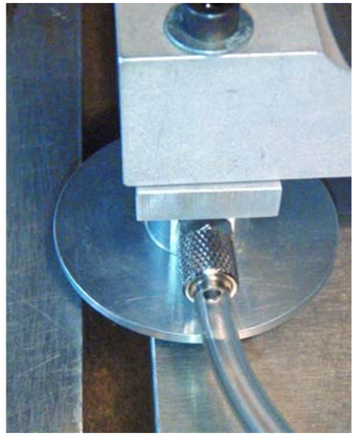
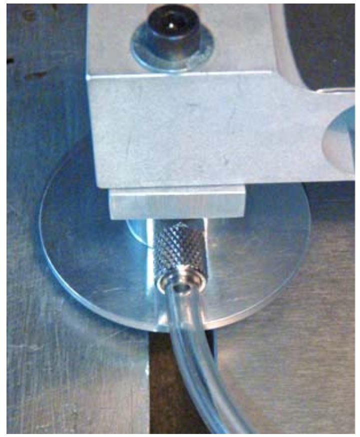

Attraction forces for different surfaces
Force / N
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
3
3.5
4
4.5
5
Pressure / bar
Glass
Polyethylene board (plastic)
Flake board (wood)
Corrugated board
Styrofoam
Rough wood
Cloth
Air cushion foil
Foam plastic
Sandpaper S600
Sandpaper S240
Sandpaper S40

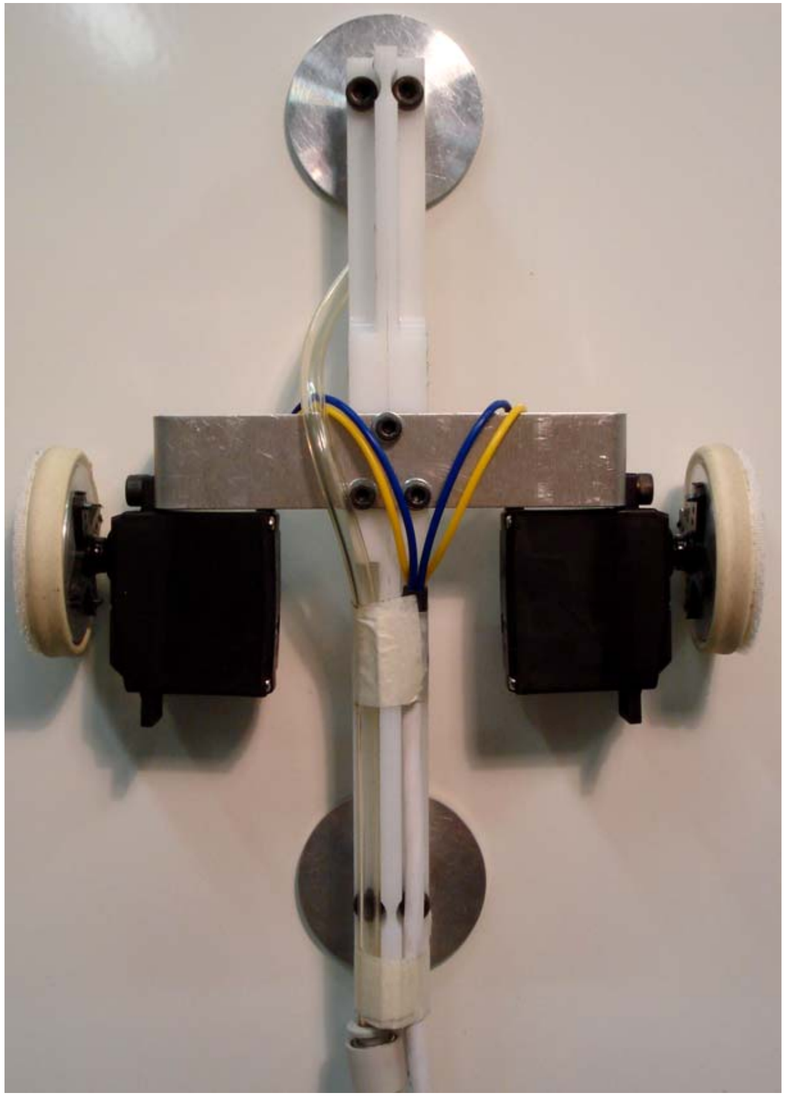
Illustration of passing a 10mm gap







The Prototype Robot



Parts:

1 Plastic as main body

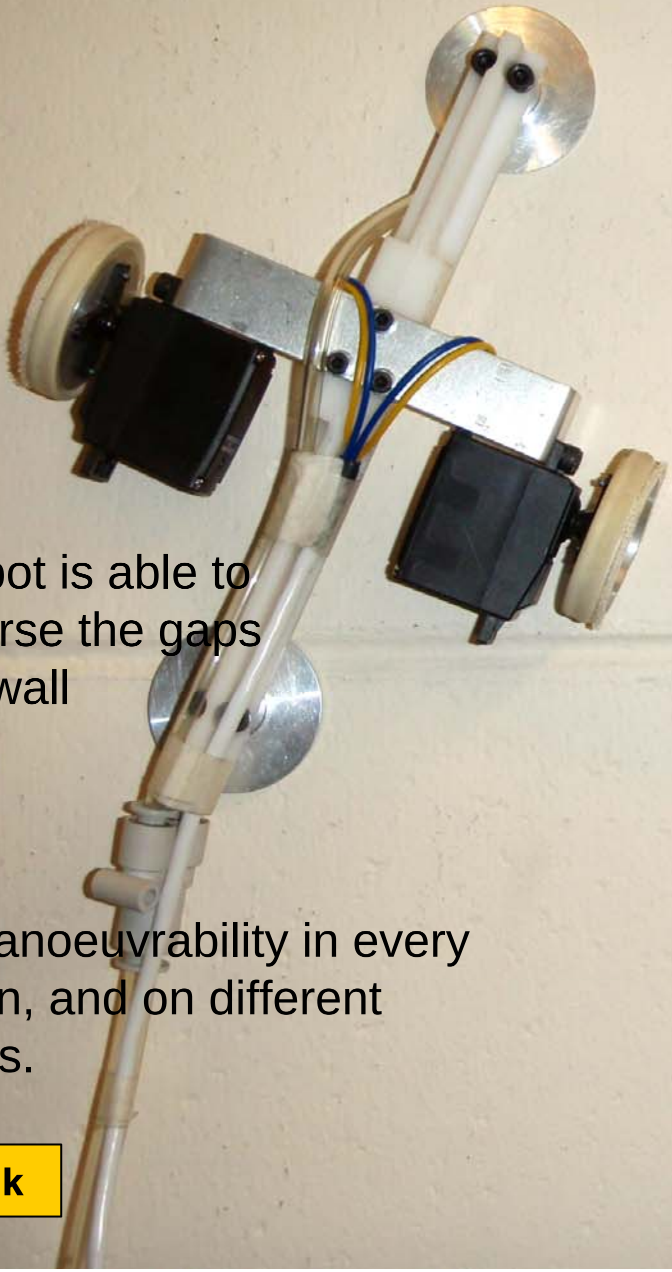
2 Bernoulli Pads

1 Aluminium suspension beam

2 Servo drive trains

2 Aluminium wheels with high friction tires (friction coefficient 0.74 on glass)

UC Wall-Climbing Robot - Performace



The robot is able to transverse the gaps on the wall

High manoeuvrability in every direction, and on different surfaces.

Total weight: 234g
Max attraction force (at 5 bar): 12N

Additional weight that can be lifted (on a wall as on a ceiling): 500g

Video: Climbing different surfaces and ceiling

Back

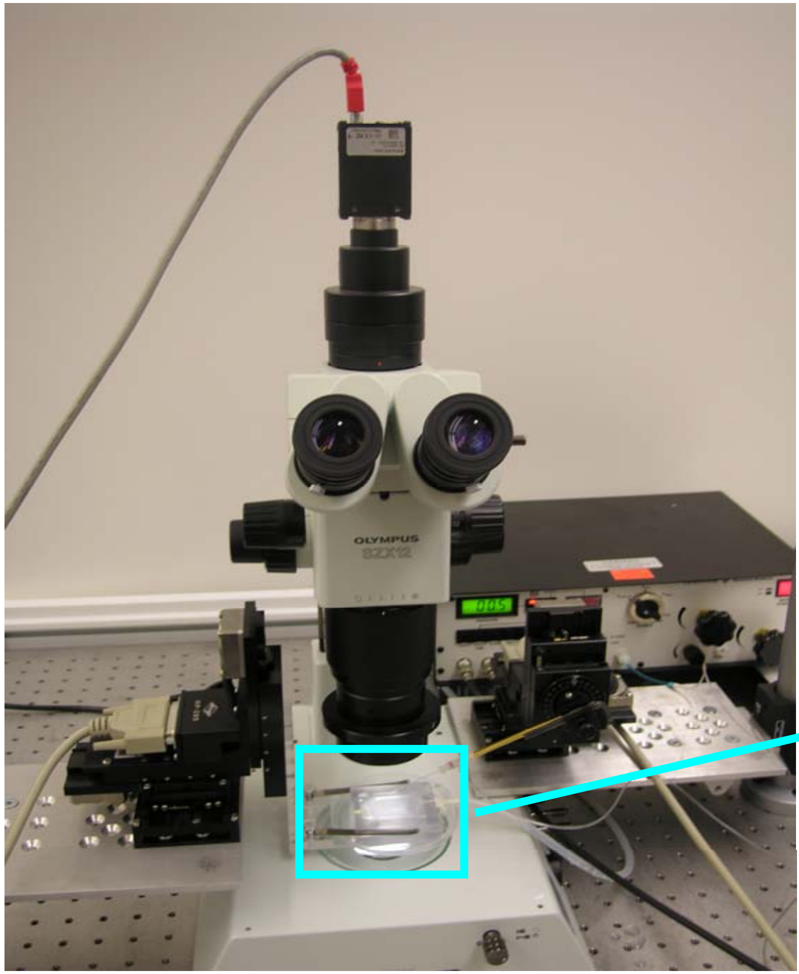
Microrobotic Cell Injection

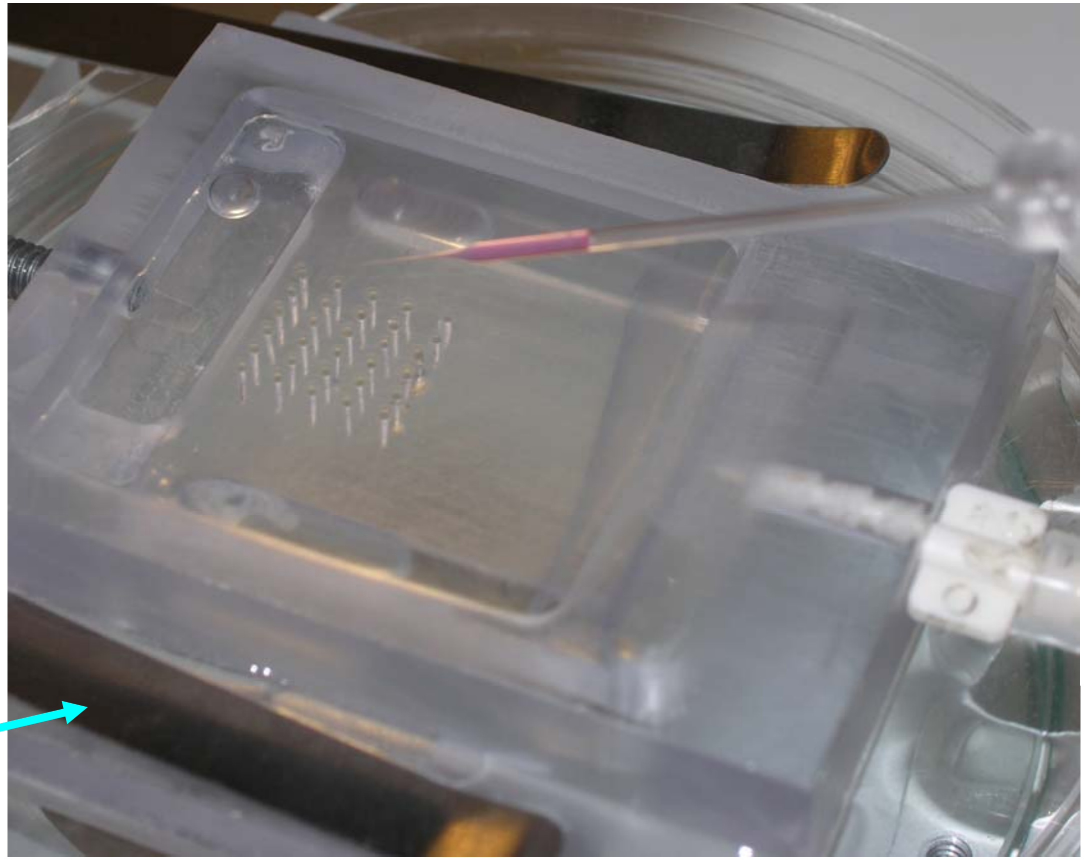
- Cell Patterning
- Determine 3D information from 2D imaging
- Cell Injection

Wang, WH, Hewett, D, Hann, CE, Chase, JG and Chen, XQ (2008). “Machine vision and Image Processing for Automated Cell Injection,” Proc 2008 IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA08), ISBN: 978-1-4244-2368-2, Beijing, China, October 12-15, pp. 309-314.

Microrobotic Cell Injection System

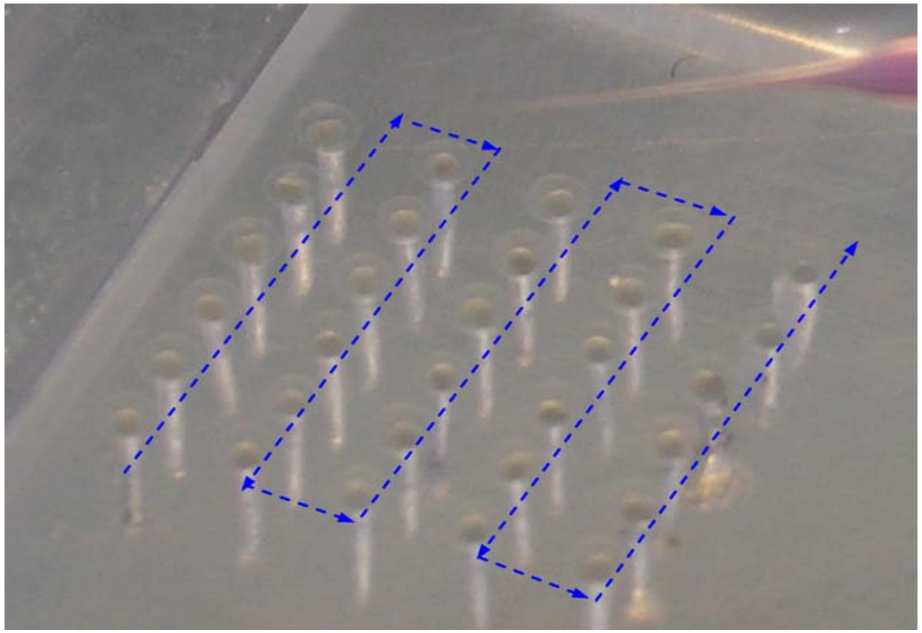
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

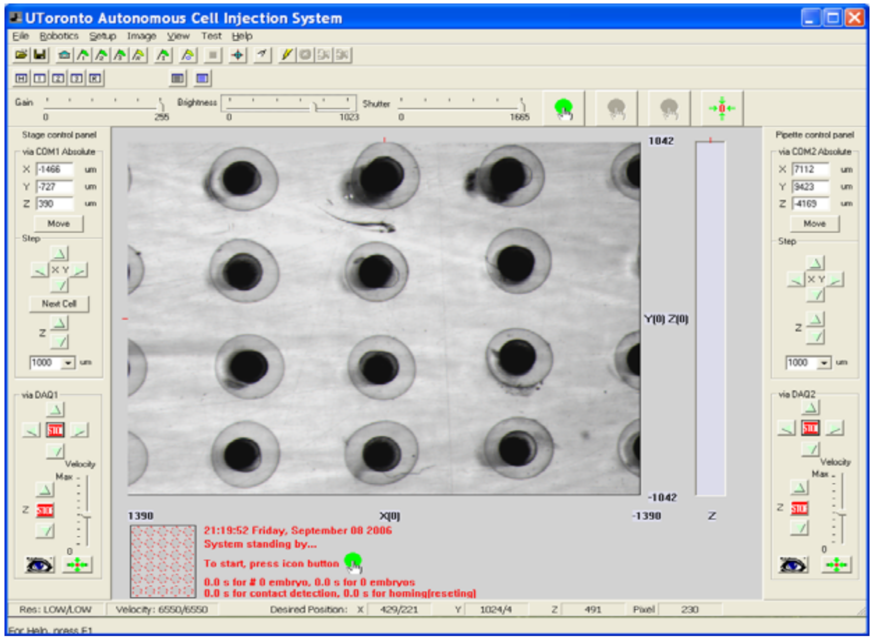




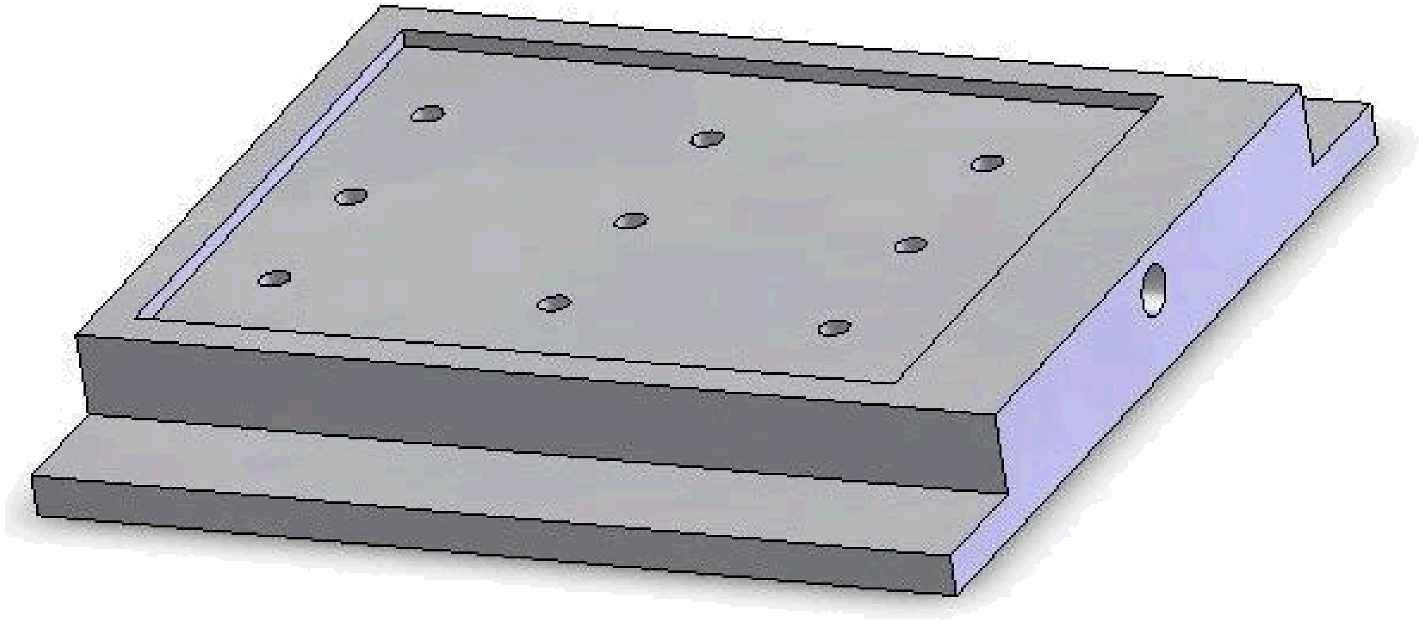
Challenges to Tackle

- Immobilize a large number of cells into a regular pattern
- 3D manipulation with 2D microscopy visual feedback
- Robust image processing
- Coordinately control two microrobots
- Optimization of operation parameters to minimize lysis

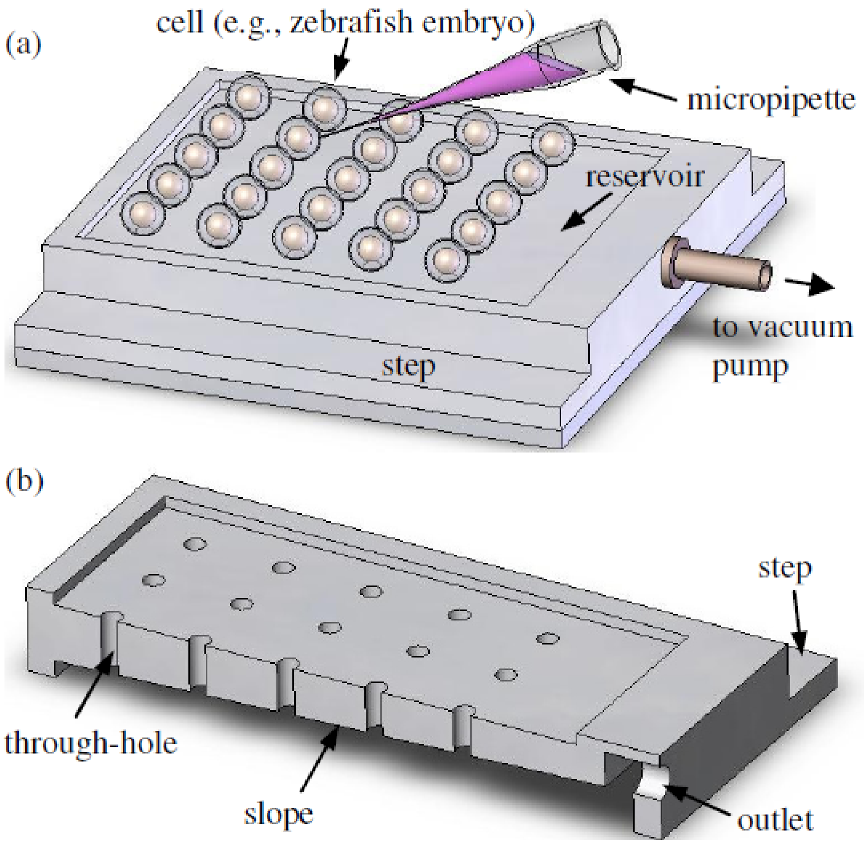


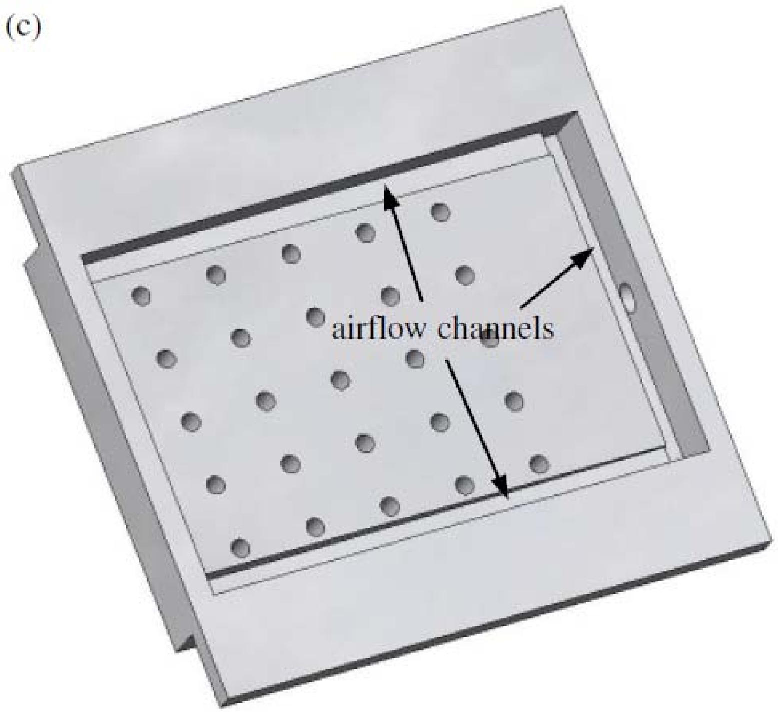


Embryo Holding Device

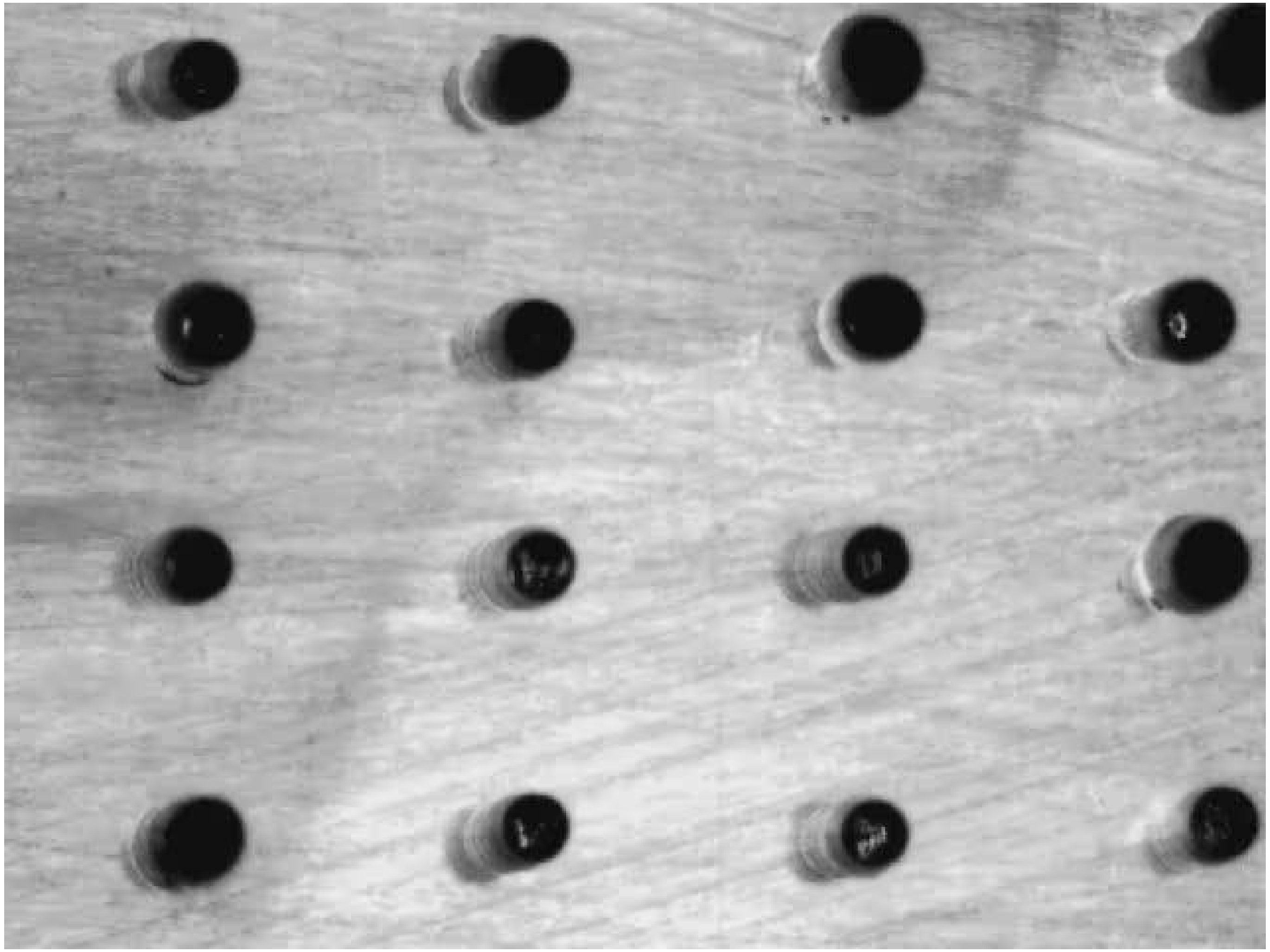


Detailed structure

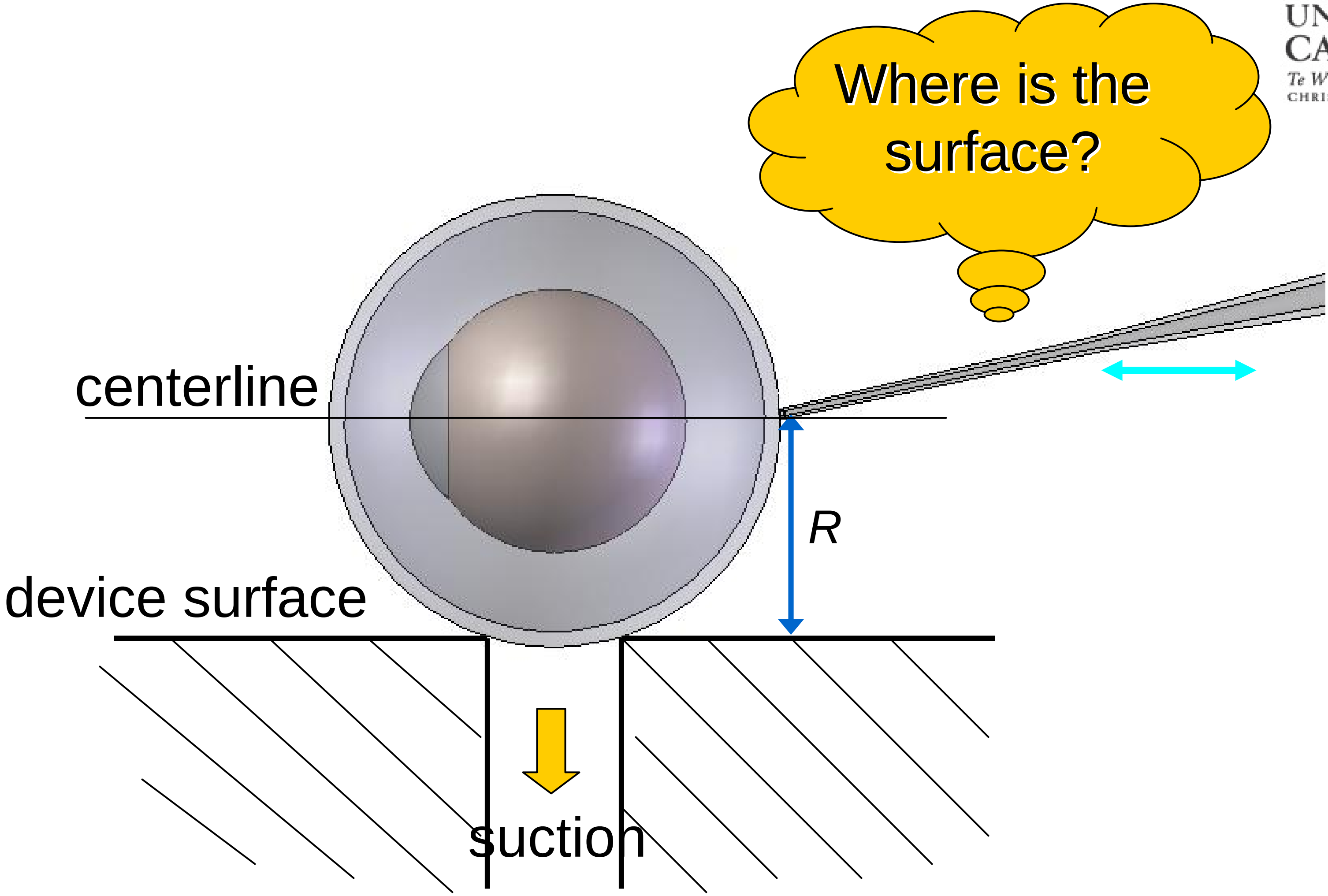




Sample Preparation

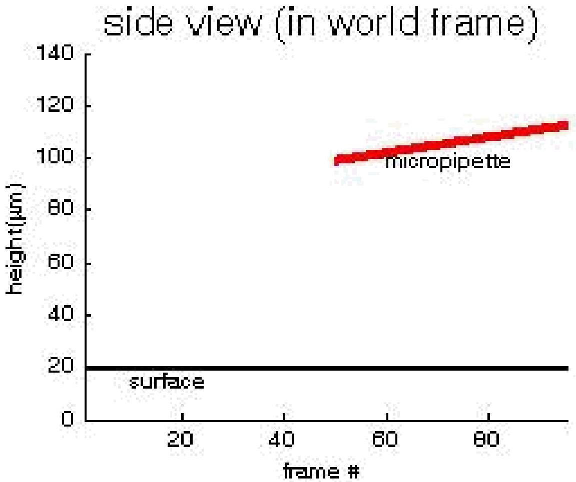


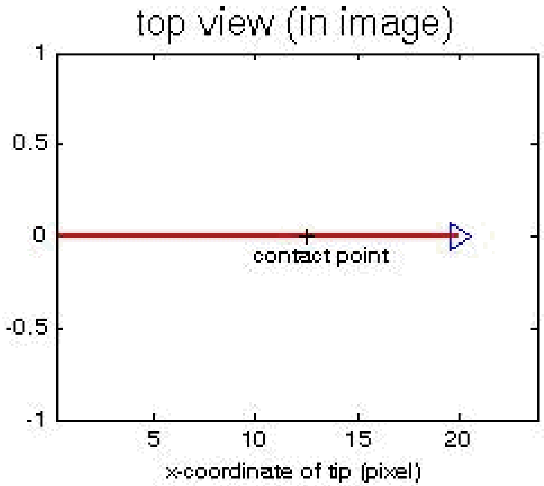
Contact Detection



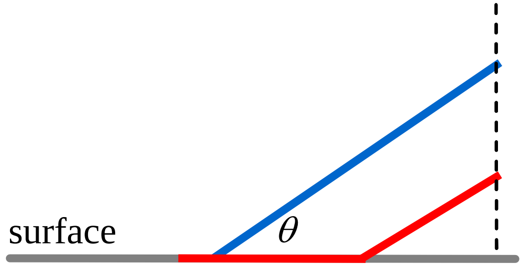
Can we get 3D (Z) information from 2D (image plane x-y) information?

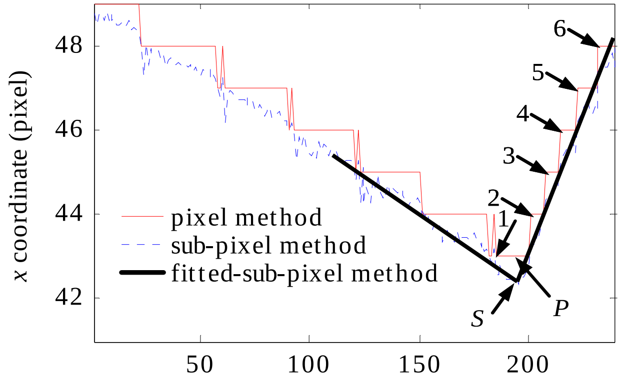
Contact Detection Principle





contact detection procedure animation



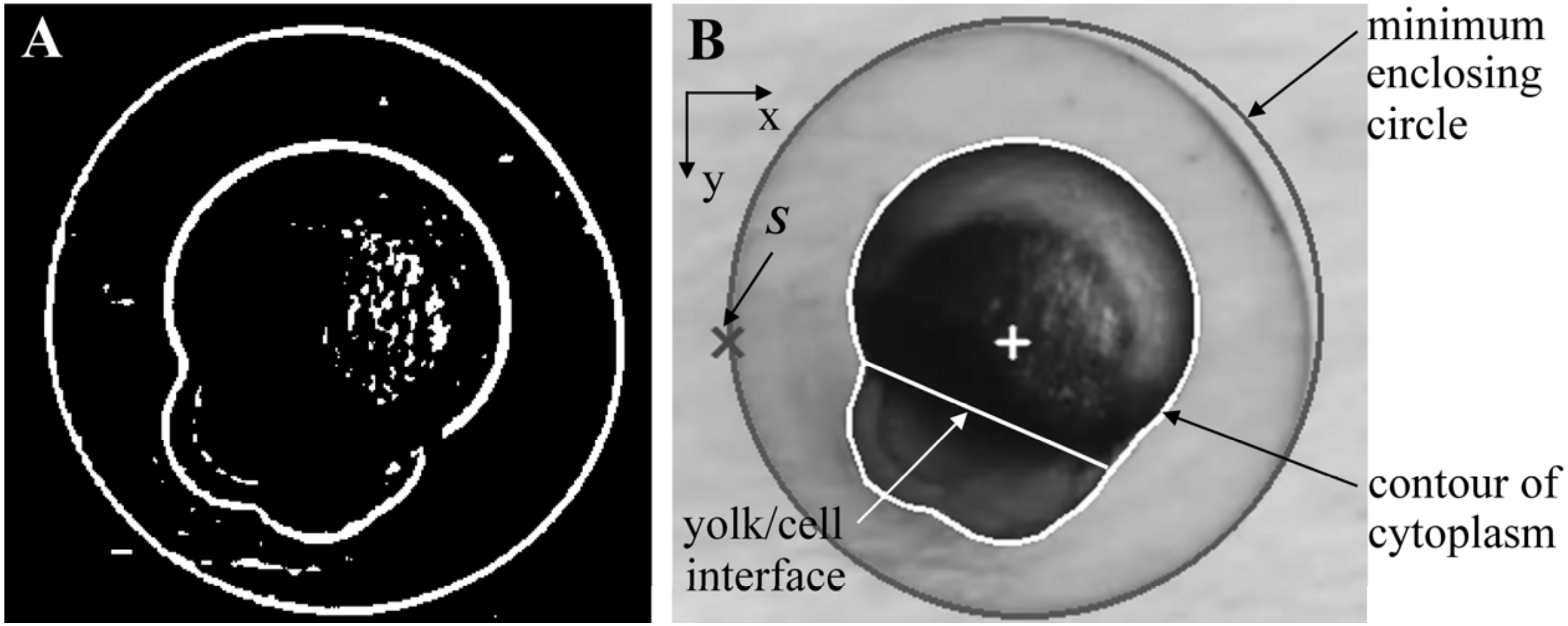


real case

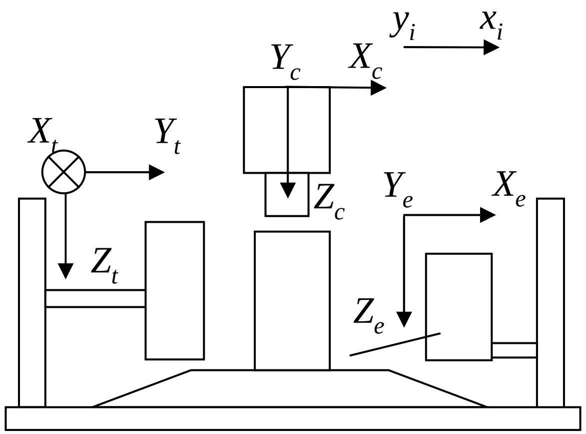
Int. J. Robot. Res., 26, 2007

Recognition of Embryo Structures

- Adaptive thresholding and morphological operations
- Snake tracking and convex deficiency calculations
- Recognition of chorion, cell, yolk, and cytoplasm center



Coordinate Frames & Transformation



$$^{e}R_{c} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

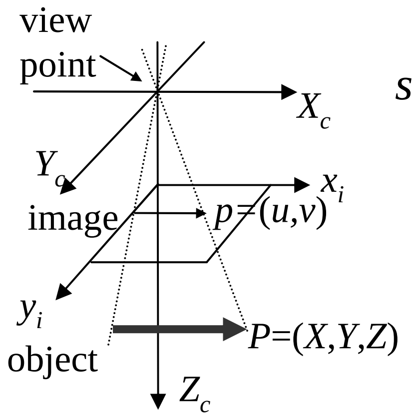
$$^{t}R_{c} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

microrobotic frames vs. camera frame

$$^{e}P = {}^{e}R_{c}\,{}^{c}P + {}^{e}t_{c}$$

$$^{t}P = {}^{t}R_{c}\,{}^{c}P + {}^{t}t_{c}$$

(1)



$$s = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix}$$

$$s\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} X \\ Y \end{bmatrix}$$

$$s\,{}^{i}p = {}^{c}P \quad (1)$$

microrobotic frames vs. image frame

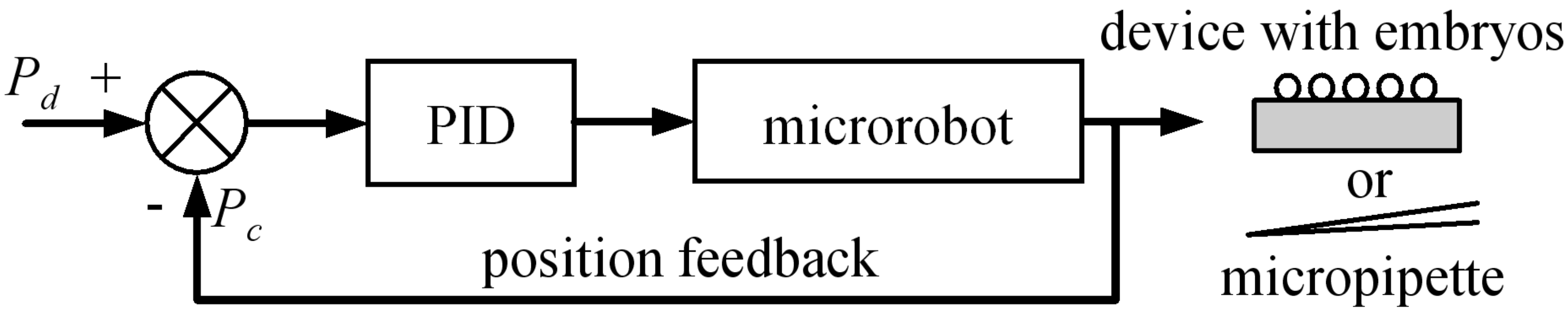
$$^{e}P = {}^{e}R_{c}\,s\,{}^{i}p + {}^{e}t_{c}$$ tip home position

$$^{t}P = {}^{t}R_{c}\,s\,{}^{i}p + {}^{t}t_{c}$$ initial cytoplasm centroid

?

Looking-then-Moving

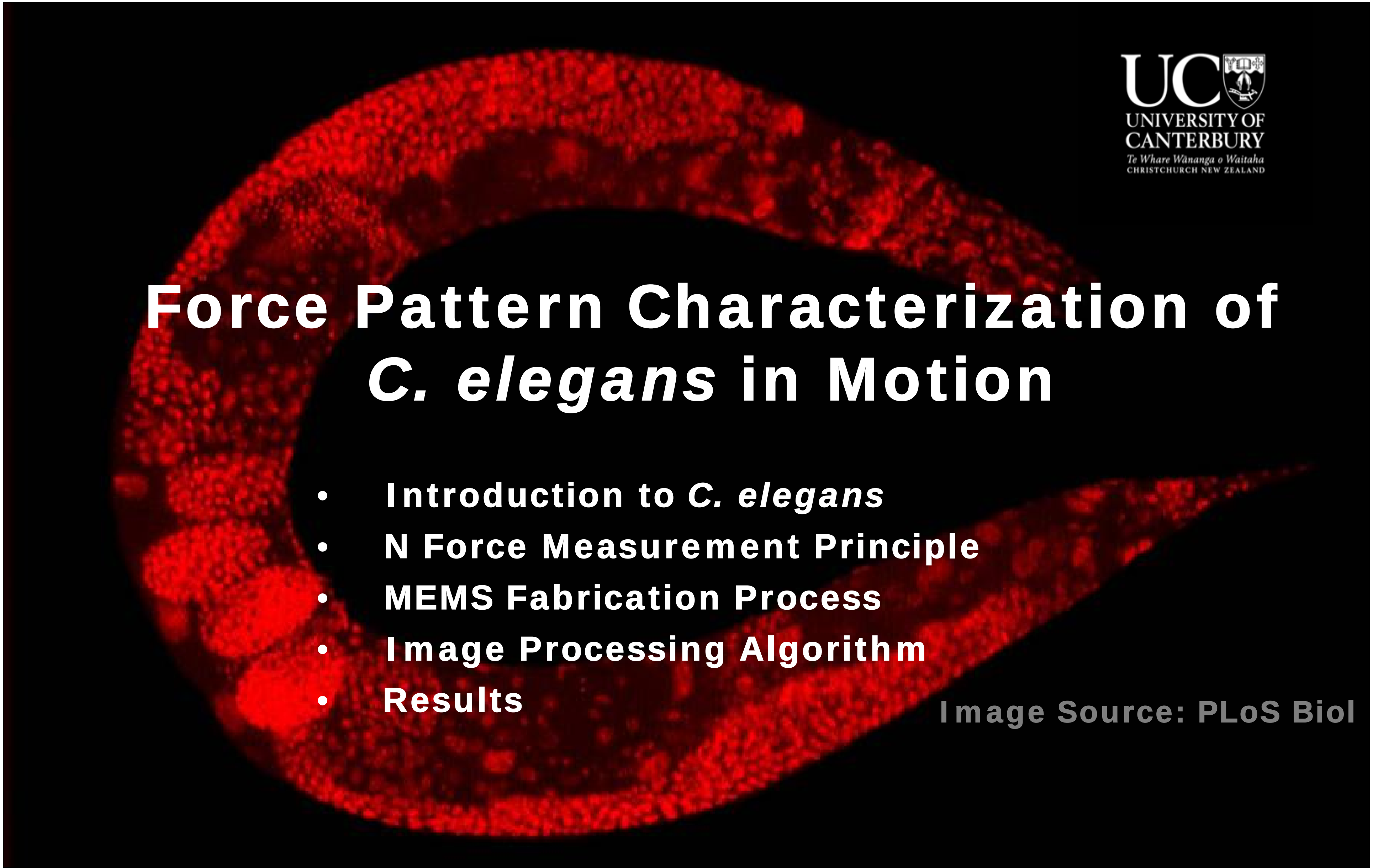
- Looking in image for initial positions of:
  - the tip
  - the deposition point
- Where to move in microrobotic frames?
  - coordinate frame transformation
- How to move?
  - position feedback from microrobots only



Injection Control Sequence

contact detection → batch injection

Back



UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Force Pattern Characterization of *C. elegans* in Motion

- Introduction to *C. elegans*
- N Force Measurement Principle
- MEMS Fabrication Process
- Image Processing Algorithm
- Results

Image Source: PLoS Biol

Ali Ghanbari, Volker Nock, Wenhui Wang, Richard Blaikie, J. Geoffrey Chase, XiaoQi Chen, and Christopher E. Hann (2008). “Force Pattern Characterization of C. elegans in Motion”, 15th Intl Conf on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, Dec 2-4,CD-ROM.

C. elegans – Locomotion

C(aenorhabditis) elegans

- free-living nematode (roundworm)
- about 1 mm in length, 100µm in width
- lives in temperate soil environments
- used extensively as a model organism

C. elegans was the first multicellular organism to have its genome completely sequenced (1998)

Challenging because:

- *C. Elegans* are very small**:**
  - **cannot use conventional force measurement techniques**
- *C. Elegans* are living organisms**:**
  - **non-intrusive measurement technique required**

Cellular Force Modelling

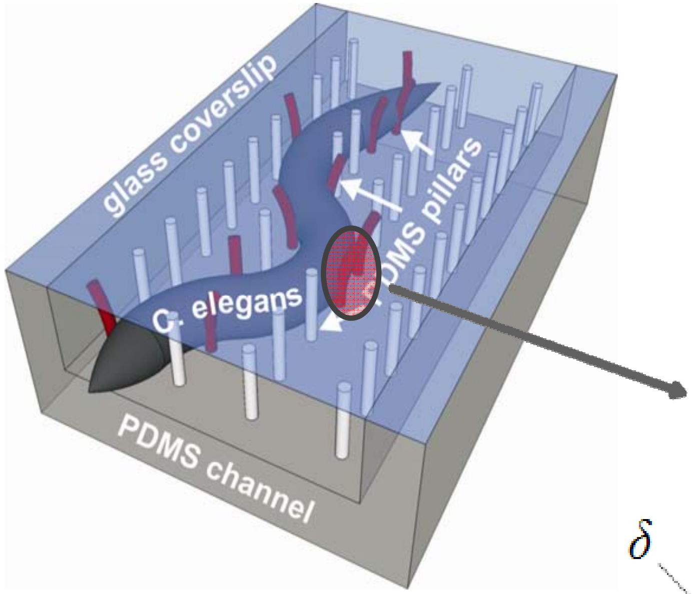
- At force point:
  Bending + Shear

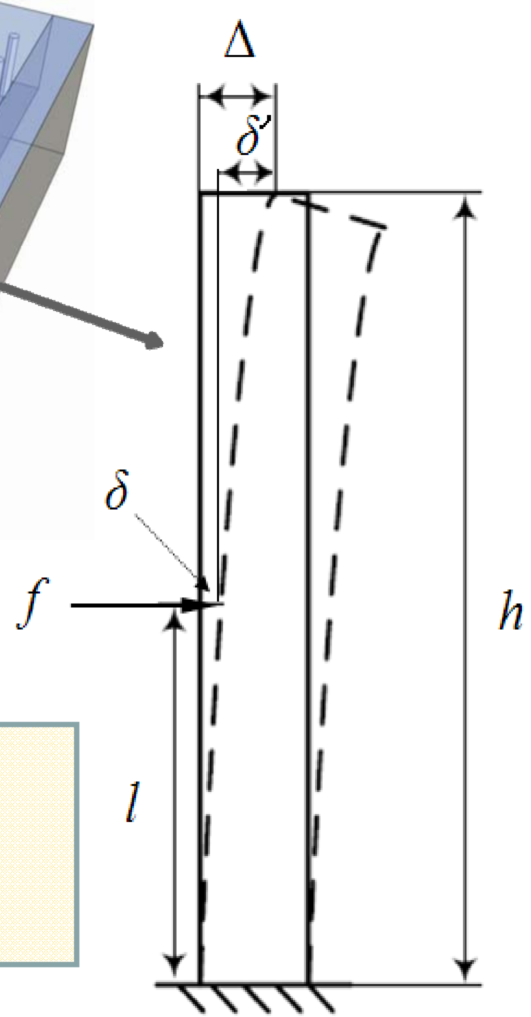
$$\delta = \left(\frac{l^3}{3EI} + \frac{20(1+\gamma)l}{9AE}\right).f$$

- From force point to the free end of the pillar:
  Just Bending

$$\delta' = \frac{l^2}{2EI}(h-l).f$$

I: moment of inertia
E: Young's modulus
Y: Poisson's ratio

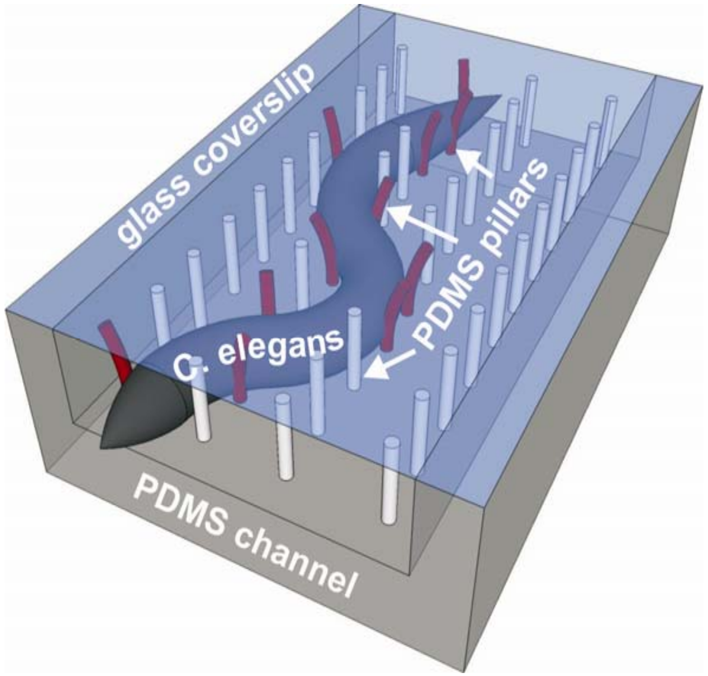




$$\Delta = \delta + \delta'$$

$$f = \frac{\Delta}{\left(\frac{l^3}{3EI}+\frac{20(1+\gamma)l}{9AE}\right)+\frac{l^2}{2EI}(h-l)}$$

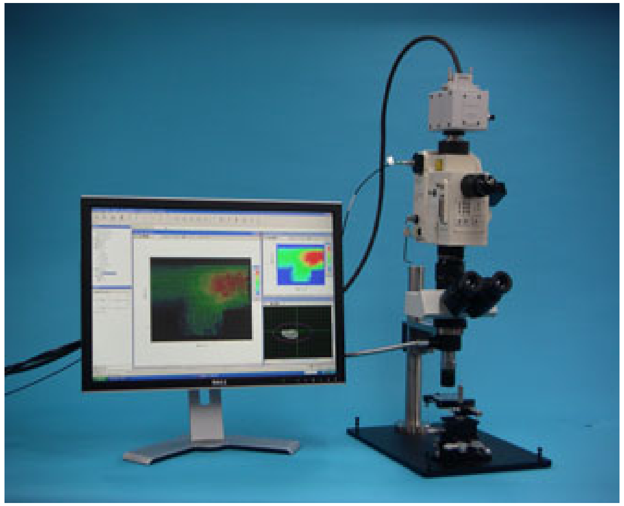
Detecting Pillar Deflection



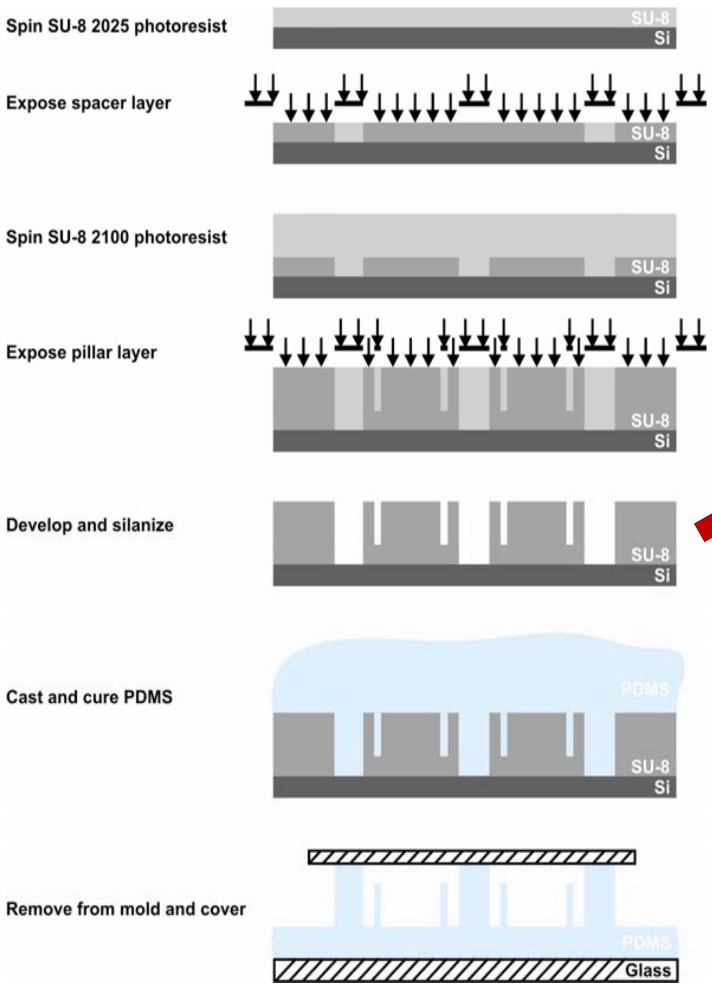
Parameters for Pillar Array:

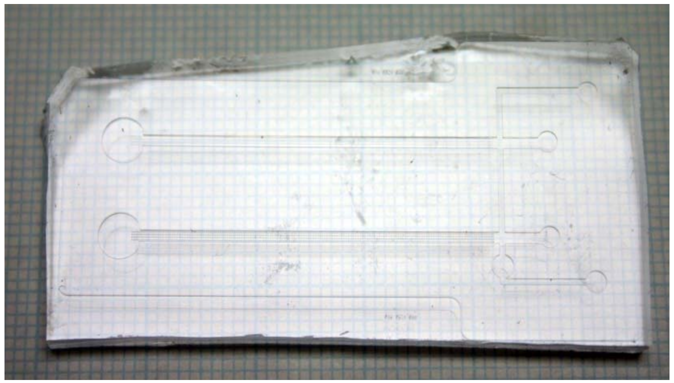
- stiffness of silicone
- pillar diameter
- spacing
- height

✚ Image capture and processing setup



MEMS Fabrication





Device Molds

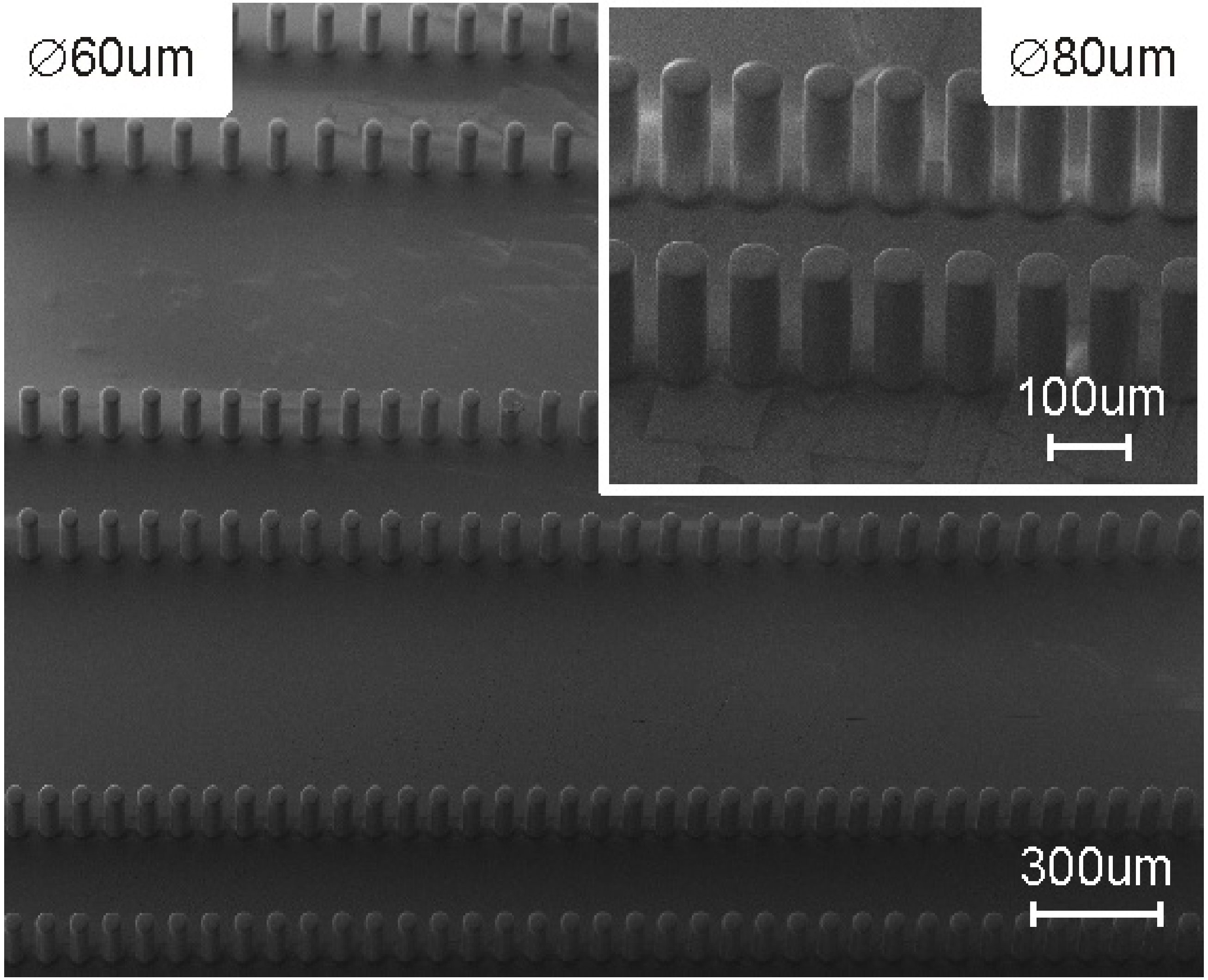


Image processing

- Without loss of generality, three specific pillars targeted for image processing
- Frames converted to black and white to have binary images
- Three zones defined to extract each pillar image in an assigned square window
- A Boundary Tracing Algorithm developed and adapted to trace the outline of the outer circle of the deflected pillars

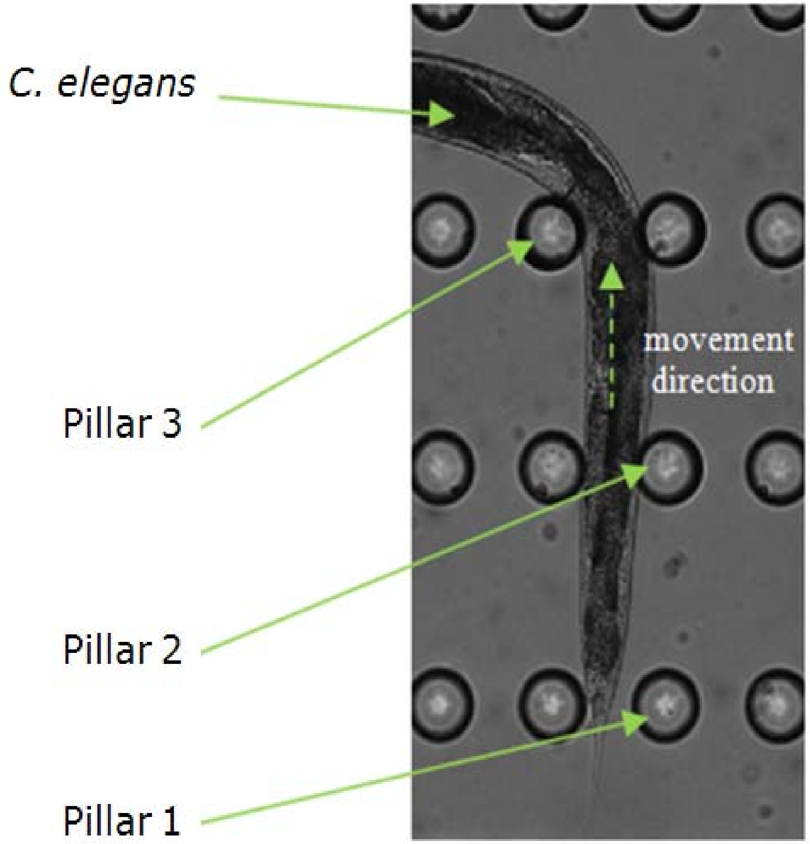


Image processing Algorithm

- Scanning the square window from bottom left: P0
- Searching the 3×3 neighborhood of the current pixel in an anti-clockwise direction.
- The circle point tracing is repeated up to detecting nth pixel Pn .

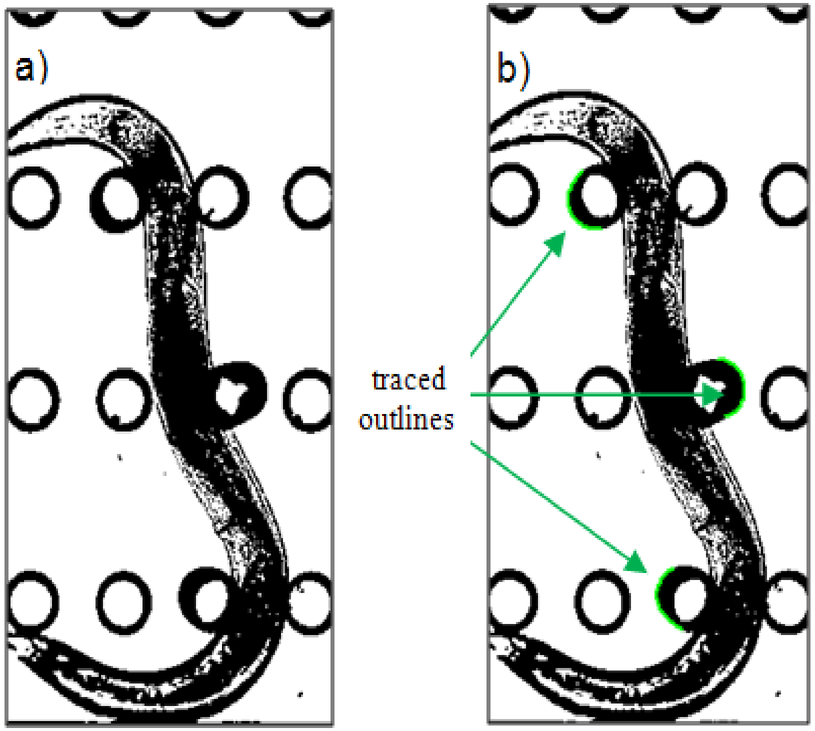
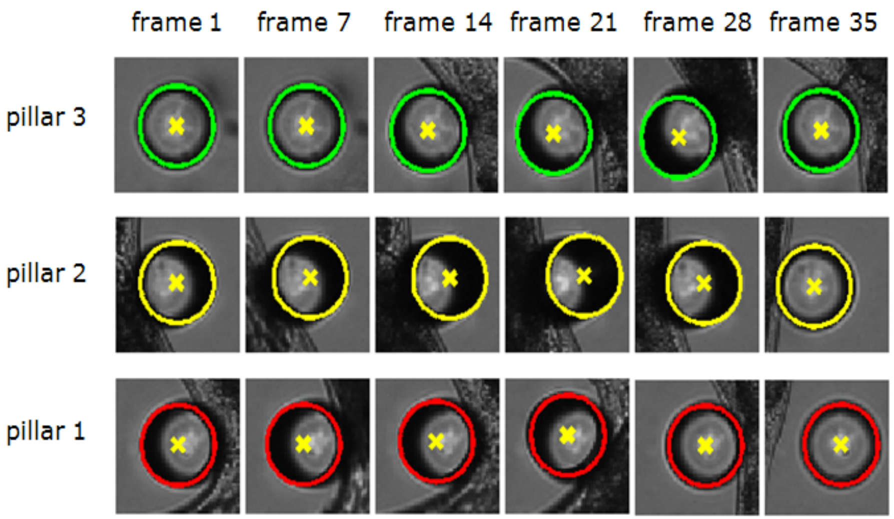
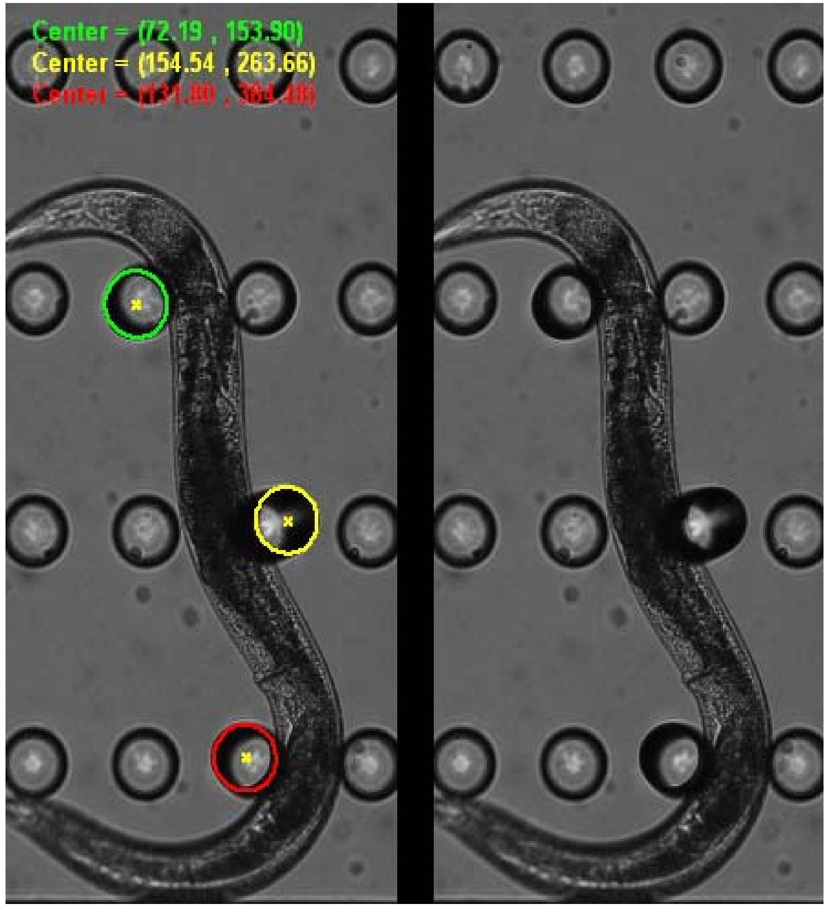


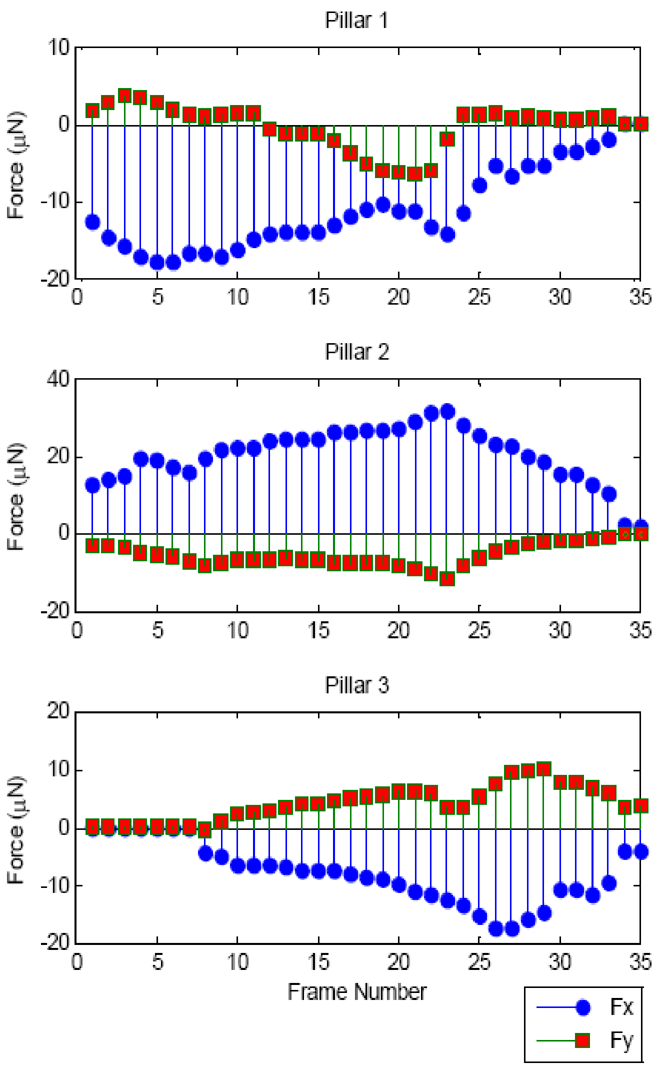
Image processing Algorithm

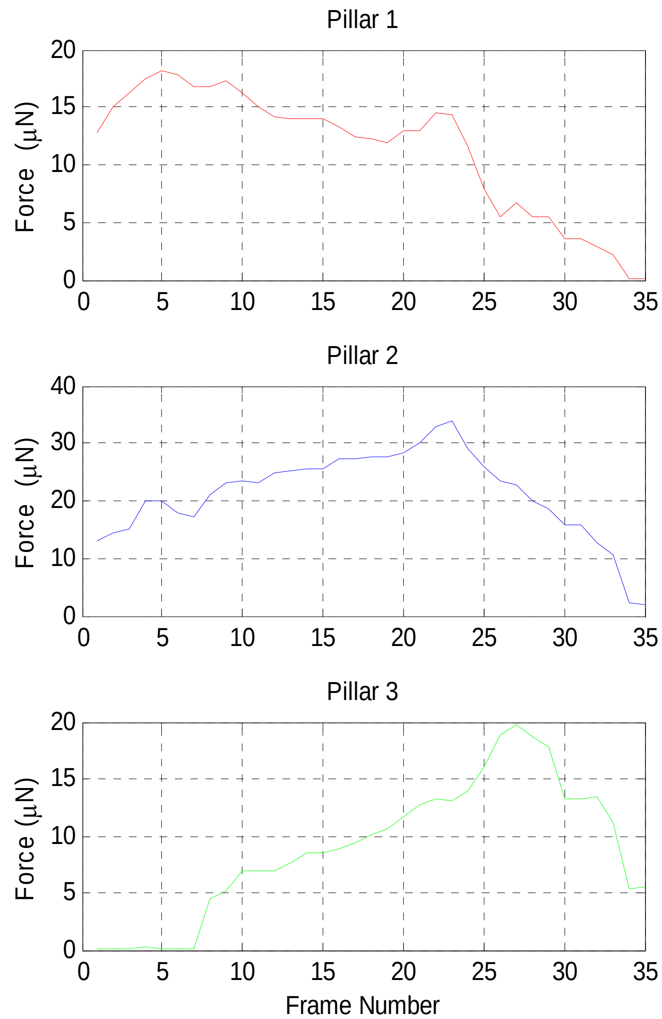
- A least-square fitting algorithm was employed to fit a circle to the traced points





MAX FORCE	PILLAR 1	PILLAR 2	PILLAR 3
$\|f_x\|$ (μN)	17.93	31.85	17.48
$\|f_y\|$ (μN)	6.58	11.52	10.08
$\|f\|$ (μN)	18.15	33.87	19.76

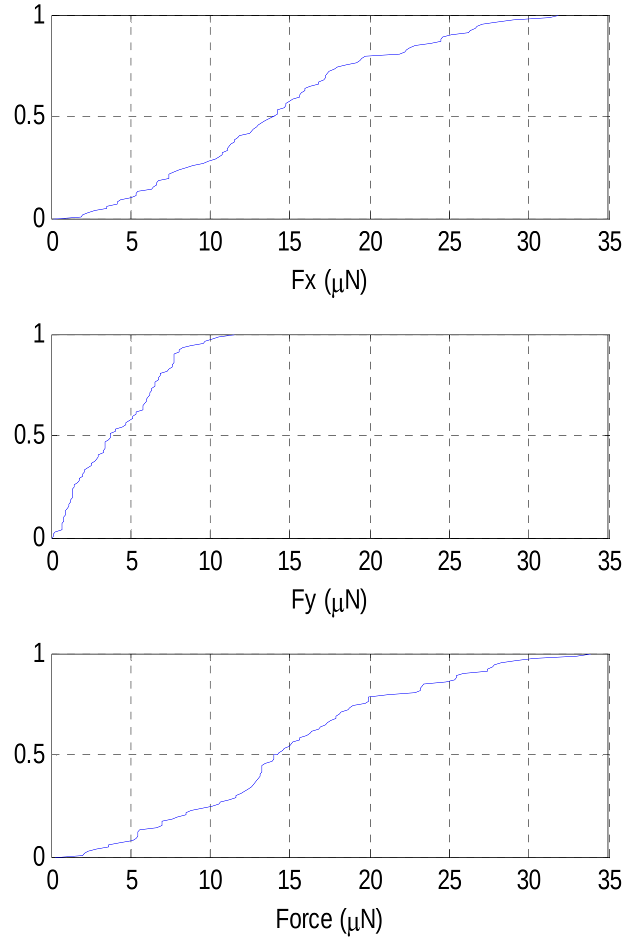




Cumulative Distribution of Calculated Forces

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

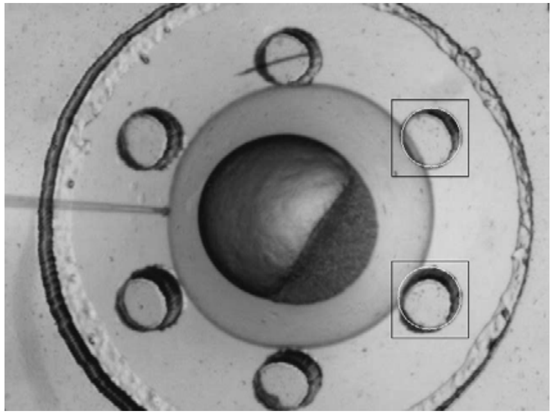
- Sorting the all calculated forces of three pillars except zero ones from smallest to largest and distributing them between 0 to 1 with steps of one over the number of sorted forces.
- A nearly linear cumulative distribution function (CDF) will be obtained, which implies an approximately uniform distribution of forces.
- It shows a highly variable and continuous force level produced by the worm, which is in accordance with biological results and the anatomy of *C. elegans.*

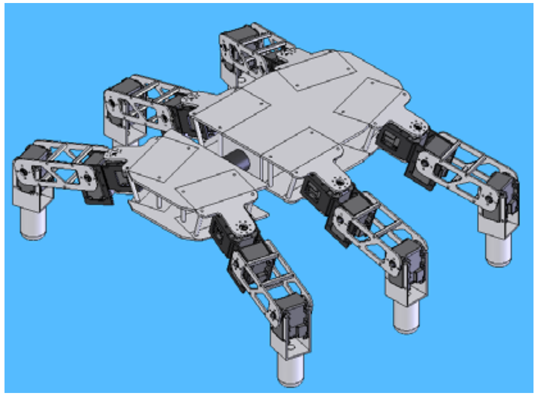


Back

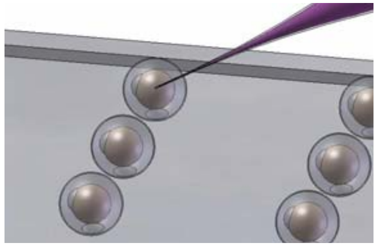
Conclusion & Future Work

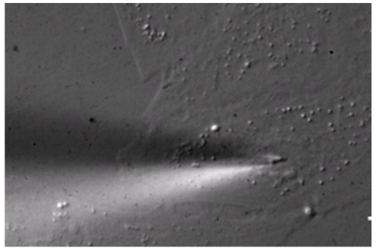
- Assistive robotic devices
  - Prosthetics, Rehabilitation
  - Active assistant
- Biologically inspired robots
  - Biomimetics study
  - Novel micro actuator and mobility control
  - Situational awareness (feeler, vision, tactile, sound)
- Human machine interface technology
  - Augmented reality
  - Haptics device for virtual presence and virtual training
  - Brain-computer interface
- Mobile robotics
  - Mobility: hybrid wall climbing mechanism (Bernoulli pad++), untethered
  - Sensing: vision for motion sensing in place of expensive IMU
  - Environmental / resource measurement, monitoring
  - Automating complex tasks in natural environment.
- Energy harvesting
  - Convert mechanical energy to electric power. Cost & efficiency.
  - Self-powered wireless instrument

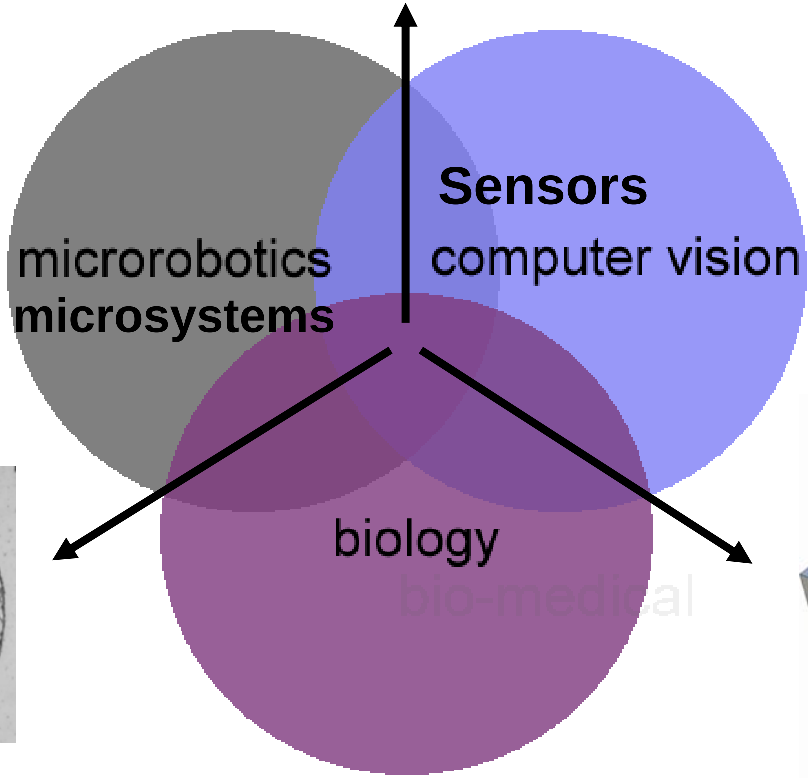


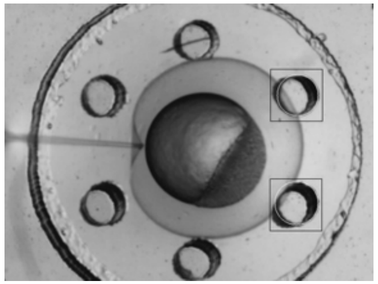


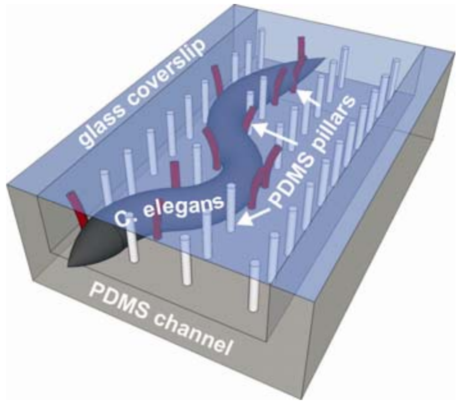
Biomechatronics











Questions ?